IOBC / WPRS

Working Group "Integrated Control in Glasshouses"

OILB / SROP

Groupe de Travail "Lutte Intégrée en Cultures sous Verre"

CONTRIBUTIONS WORKING GROUP MEETING

at

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Address General Secretariat:
INRA Station de Zoologie
Domaine Saint-Paul
Site Agroparc
84914 AVIGNON Cedex 9
France

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PREFACE

This bulletin contains the **precedings** of the 9th full meeting of the working group "Integrated Control in Glasshouses". Many members of our working group have grown used to the habit of providing and publishing the papers before the meeting, so that the discussion sessions can be prepared efficiently. This time most papers arrived well in time and were much better prepared than previously for which I am particularly thankful, because editing and retyping took less time. Some papers had to be reduced from many to 4 pages, I hope that I was able to keep the main message of these papers intact.

We have tried to create more intensive cooperation with two other working groups of IOBC/WPRS (resistance breeding and biological control of diseases), but disappointingly few papers were provided. Also, the producers of natural enemies were not very active in writing papers for this meeting. Nevertheless, more than 50 interesting articles are included in this bulletin: a respectable production of working group members. And, in addition, one attempt to improve cooperation succeeded very well. By request of the Council of the International Organization for Biological Control (WPRS), a new study group has been established on the issue of quantitative approaches in IPM to address two topics. The first objective is to identify (mis)matches between supply and demand for decision support systems in different cropping/farming systems. The second objective is to stimulate a critical evaluation of the biological contents, modelling concepts and range of validity of pest population models, developed over the last 15 years. The ultimate objective is to improve the usefulness of systems research as a support for pest management decision making at field, farm and policy levels.

To optimize integration with existing IOBC groups the study group aims at organizing sessions as part of the regular meetings of commodity-oriented IOBC working groups. Like in 1987 at the Budapest meeting and in 1990 at the Copenhagen meeting, we will dedicate time to the role of modeling for IPM during the Vienna meeting in May 1996, but this time the modeling session will be organized by the convener of the specific study group. We will try to have a "hands on" session, where working group members can try out several models.

The organization of a full meeting is not an easy task. This time, organization went very smoothly, because of the excellent work of Dr. Sylvia Blümel (Institut für Phytomedizin, Vienna, Austria). Sylvia was and is responsible for local arrangements and coordination of the meeting, and the arrangement of a full day field excursion. On behalf of the 90 participants, I like to thank her cordially for all the work she was willing to do to make the meeting a success!

J.C. van Lenteren
Convener IOBC/WPRS Working Group
"Integrated Control in Glasshouses"
30 January 1996

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The mirid bug *Dicyphus tamaninii* : an effective predator for vegetable crops

R. Albajes[1], O. Alomar[2], J. Riudavets[2], C. Castañé[2], J. Arnó[2] & R. Gabarra[2]
[1]Centre UdL-IRTA, Rovira Roure 177, 25006 Lleida, Spain
[2]IRTA, Centre de Cabrils, 08348 Cabrils(Barcelona), Spain

ABSTRACT. Several mirid bugs are native polyphagous predators in the Mediterranean basin, and among them, *Dicyphus tamaninii* is of particular interest. In the present contribution main biological features, prey range and consumption rates of *D. tamaninii* preying on whiteflies (*Trialeurodes vaporariorum* & *Bemisia tabaci*), *Frankliniella occidentalis* and aphids (*Macrosiphum euphorbiae* & *Aphis gossypii*) are reviewed. Use of the predator for biological control programmes by conservation or augmentative releases are discussed.

1. Introduction. Miridae form the largest family in the Heteroptera (Dolling 1991) and several species have been successfuly used in biological control of insect pests. In Europe and particularly in the Mediterranean basin, several predatory mirid bugs have been cited, among them *Dicyphus tamaninii* Wagner (DT)(Goula & Alomar, 1994). In the early 80's, DT was signaled as the main responsible for low pest densities in the field when insecticide pressure was decreased on tomatoes. Exclusion cage experiments confirmed that whitefly population reduction was caused by this predator (Gabarra *et al.* 1988). Since then, DT has been used in biological control programmes by mirid conservation (Alomar *et al.* 1991) and new research has confirmed the usefulness of DT as biological control agent in a broad spectrum of vegetable crops. In the present contribution we review the current state of the knowledge on DT and discuss its usefulness for biological control.

2. Main biological features. Although DT is successfully used in the framework of IPM systems (Alomar *et al.* 1991), little is still known about the main features of its biology and ecology.
Distribution on the plant: Females lay eggs in stems, leaf petiols and principal veins. On mature tomato plants, nymphs and adults are more frequently found on the middle leaves (Alomar, 1994) and we have observed a similar **vertical distribution** on tobacco.
Fecundity is quite variable in laboratory tests according to the plant species and prey. On pelargonium plants, a total number of 88 eggs (mean of 3.5 eggs/48 hours) were laid by females that had been reared on greenhouse whitefly (Riudavets & Castañé, non published results). Big and significant differences in fecundity were found when sweet pepper, cucumber and two tomato cultivars were compared as host plants for laying eggs (Riudavets 1995).
Developmental time lasted 12.1 days for eggs and 18.9 days for nymphs when these were allowed to prey on western flower thrips at 25°C (Riudavets, 1995). On greenhouse and sweetpotato whifelies, DT nymphal development lasted 21.8 (at 22°C) and 20.2 (25°C) days respectively (Salamero *et al.* 1987 and Barnadas 1994 respectively). **Longevity**: measurements rendered very variable [14.7-27.7 (95%)] values (Riudavets 1995).
Temperature effects: No reliable data on DT tolerance to high temperatures are available, but DT was preying on greenhouse whitefly when the temperature was almost 40°C, so the upper lethal threshold will be above 30°C. Observations indicate that DT adults prey on sweetpotato whitefly and oviposit under winter-simulated conditions [thermoperiod of 16(14,5h)/11(9,5h)°C (14,5L/9,5D daylenght)] (Arnó & Gabarra, non published results).

3. Native and crop plants on which DT has been found. No systematic work has been

done on DT **overwintering** stages but both nymphs and adults have been observed during the winter in warm coastal localities (Alomar 1994).
Results of sweep-net samples taken from October to May on cultivated and non-crop vegetation showed that DT can be found on a wide variety of plant refuges (Alomar 1994). *Parietaria officinalis* and *Cistus spp.* are common refuges of the mirid bug throughout the winter, so that the role of these plants as DT sources for early spring colonization of vegetables may be emphasized (Alomar *et al.* 1994). This mirid bug has been also found on: tomato, potato, cucumber, french bean, tobacco, strawberry, lettuce and peppers (Riudavets *et al.* 1993, Alomar 1994, Riudavets 1995).

4. Prey range and consumption. DT is a generalist predator both in the laboratory and in the field feeding on a variety of prey: eggs, larvae and adults of both greenhouse and sweetpotato whitefly (Barnadas 1994), *Liriomyza* larvae, lepidopteran eggs (Salamero *et al.* 1987), larvae of western flower trips (Riudavets, 1995) and aphids (*Aphis gossypii* and *Macrosiphum euphorbi*ae)(Alomar, Alvarado & Fenili, non published results). DT is a voracious predator; some of the daily average consumption rates measured by authors are presented in Table 1.

5. Predatory *vs.* plant feeding habits. Several generalist bugs feed on plant products (Dolling 1991). This ability may be important for sustaining both adults and nymphs when prey is scarce (Ehler 1990). Plant feeding by predacious mirids has been related to shortage of alternative insect prey rather than to mirid density (Salamero *et al.* 1987, Malausa 1994, Alomar 1994, Barnadas 1994). Whole plant samples on tomato shows that up to 80 DT per plant do not affect vegetative growth (Alomar 1994), but when prey are scarce DT can puncture tomato fruits and cause cosmetic damages on marketable yield. On cucumber, however, the coincidence of high mirid populations with extremely low prey populations did not conclude in fruit damage (Gabarra *et al.* 1995). Risks of damage caused by mirids on vegetables must be evaluated carefully because many factors can influence the result of the plant, pest and mirid relationship: plant species and variety and mirid/ prey ratio, among other.

DT stage	Prey/ stage	Consumption rate/ 24 h.	Host plant	Ref
adults	*Trialeurodes vaporariorum* Last instar larva	15.0	Tomato	1
adults	*Bemisia tabaci* Last instar larva	12.1	Tomato	1
nymphs	*Frankliniella occidentalis* Larva	12,7	French beans	2
adults	*Aphis gossypii* Young nymph	43.6	Cucumber	3
adults	*Macrosiphum euphorbiae* Young nymph	42.1	Tomato	3

Table 1. Consumption rates of *Dicyphus tamaninii* (DT) preying on several prey species in no-choice tests at 25°C. References: 1. Barnadas, 1994. 2. Riudavets, 1995. 3. Alomar, Alvarado & Fenili, non published results.

6. DT for biological control by conservation. DT is found in several Mediterranean areas and can colonize vegetable fields and greenhouses if unsprayed. An IPM programme for outdoor tomato crops was implemented by us on the basis of DT (and other native predatory mirids) population management. Mirids colonize tomato crops soon after planting, especially if the surrounding flora is rich in mirid refuge-plants (Alomar 1994). Decisions on when to spray aim to maintain DT/prey population ratio below a maximal (to prevent damage caused by the mirid) and above a minimal (to prevent damage caused by insect pests, mainly whiteflies) value. This IPM programme allows growers to avoid many unnecessary insecticide sprays and enhances the beneficial activity of other native natural enemies (Alomar *et al.* 1991).
DT and *Macrolophus caliginosus* colonize most greehouse crops when IPM systems are used and. Time of arrival and colonization rates by mirids are influenced by the kind of plant habitats found in the proximity to the greenhouse (Alomar 1994). *M. caliginosus* usually enter into greenhouses earlier (since end April) than DT (since mid May). They prey on whiteflies, aphids and other insect pests and complement the control action of inoculated beneficials (i.e. *Encarsia formosa*). In IPM greenhouses, up to 67% predation of whitefly pupae has been recorded by authors. Establishment of mirids in greenhouses is presumably contributing to the success of releases of exotic natural enemies like *E. formosa.*

7. DT for inoculative biological control. Sometimes mirids arrive to slow and they have to be inoculated in the crop. Exclusion cage experiments on tomato showed that releases of DT were able to maintain whitefly densities below 5 adults/3 upper leaves from three weeks after releasing 18 DT adults when initial whitefly density was 60 adults/3 upper leaves. DT was also able to control greenhouse whitefly populations on cucumber when released at dosis of 18 last instar nymphs per 100 whitefly adults. Lower rates (3 DT last instar nymphs per 100 thrips) were sufficient to prevent western flower thrips to reach economic thresholds on cucumber three weeks after DT release and to finally suppress thrips populations 7 weeks after predator release (Gabarra *et al.* 1995). Greenhouse trials confirmed the capability of DT to control western flower thrips on cucumber when it was released at a rate of 0.3 last instar nymphs per prey. Even lower DT rates (0.1 last instar nymph/prey) may be effective enough if the predator is released when western flower thrips population is low (Castañé *et al.*, paper submitted)

8. Mass rearing. Cheap mass rearing methods are important for beneficials which have to be used in regular release programmes. To our knowledge, no specific work on DT mass rearing has been done. Our laboratory rearings and experience with commercially produced mirids allow us to point out some of the main constraints for DT mass rearing.
Oviposition substrate: DT needs green plants to lay eggs and female fecundity varies greatly from one plant species to another. Use of artificial substrates for oviposition has shown promising results (fecundity remained the same) but high egg mortalities were found.
Food consumption: DT is a voracious predator and needs to devour more than one hundred preys to complete its development and to lay eggs. This leads to high costs even if standard preys, like *Ephestia* eggs, are used.
Storage: no specific diapausing studies were done for DT, but DT seems able to arrest development for long periods with no drastic reduction of its predatory performance.

9. DT for biological control: some gaps to be filled. DT may be considered as good colonizer, is temporally persistent in several Mediterranean areas and is able to rapidly exploit a food ressource, three attributes of predators which are major biological control agents in temporary agroecosystems (Ehler 1990). Although DT density within fields can be related to abundance of surrounding vegetation (Alomar *et al.* 1994), we need to know more precisely what factors favour mirid migration into fields or greenhouses in order to predict DT effectiveness. Predator releases should only be made after crop scouting has shown that natural populations are not high enough. DT is able to prey on several pest species, but what are the mechanisms (prey abundance?, prey preference?) responsible for predator switching when more prey species occur?. In cases where prey is maintained at equilibrium densities above economic threshold (e.g. *Helicoverpa armigera* in tomato), DT effectiveness can be supplemented by specific and selective control methods. Compatibility of DT with selective chemicals is not fully known yet. When prey consumption of DT and marketed natural enemies (e.g. *Orius* species, *M. caliginosus*) are compared, the first shows better results (Barnadas 1994, Riudavets 1995). If DT has to be used for realeases, it is important to reduce mass rearing costs. Risk of fruit damage derived from the use of DT has been only prooved on a few tomato varieties, not on other crops. The success with the IPM programme for tomatoes based on managing native mirid populations has proved that use of polyphagous predators, like DT, is a holistic and realistic approach to the biological control of vegetable insect pests in the Mediterranean.

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WHAT HAPPENED TO "CAPPA" ?: THE KOPPERT EXPERIENCE

K. Altena
Koppert B.V., P.O. Box 155, 2650 AD Berkel en Rodenrijs, The Netherlands

SUMMARY
Koppert participated as adviser in the development of the 'CAPPA' programme, a decision support system for IPM in sweet pepper developed by the Research Station for Floriculture and Glasshouse Vegetables. In a follow-up project, Koppert initiated the development of her decision support system, and involved a commercial software company. Early 1996 the prototype system will be available for demonstration. The paper reviews the considerations leading to the start of the project, and addresses developments concerning software development and marketing.

THE INITIAL IDEA
After participating in the CAPPA project, a decision support system for IPM in sweet pepper developed by the Research Station for Floriculture and Glasshouse Vegetables. (Ramakers, this bulletin), Koppert B.V. took the initiative to develop her own software for crop protection. Requests from major clients were a stimulus in this direction. These clients desired to computerize, streamline and simplify the registration of observations. Some had even higher expectations, e.g. prediction of population development, or linkage with their process (climate) computer. In addition to the computerized registration, Koppert added extension aspects to the software. Although the CAPPA project was not based on market reseearch, but 'survived' a test with several pepper growers.

The Koppert software package had to display the following features:
- simple registration of observations and actions by growers and their employees;
- replacing registration by hand for MBT project (i.e. a label for environmentally friendly production resulting in a higher value crop);
- registration of pests and diseases;
- registration of all allowed chemicals and formulations;
- user friendly;
- must run on existing hardware;
- regular update of databases;
- uniform observation techniques, applicable in a range of crops;
- advice database implemented for some important vegetable crops;
- climate conditions and status of crop growth to be taken into account when advising;
- visual presentation of data (graphics, grid);
- information (and warning) on side effect chemicals on beneficials, registrations, MBT regulations, etc.

Koppert was aware that past initiatives similar to the above generally failed, among others due to lack of available time for keeping the system up-to-date.

STUDY OF FEASIBILITY AND DESIRABILITY

The project team that developed the Koppert software package consisted of field researchers, advisers and computer specialists. Some friction occurred occasionally; the wishes of the 'market' have to be considered continuously. For economical reasons some important features have not been realised in the first version, especially aspects of user friendliness and visual presentation are less than expected. Also, development of observation techniques applicable in a range of crops turned out to require more time.

PROTOTYPING AND FIELD TESTING

The aim of the software package was to offer an integrated programme. One bottleneck in this process has been the change it required in the way growers carry out observations and registrations: vague categories had to become concrete numbers, occasional inspections had to become disciplined sampling. This is absolutely necessary when computerizing. A slower introduction and change could have helped in adopting the new way of thinking, and hence a greater demand for these systems.

Researchers from Research Station for Floriculture and Glasshouse Vegetables Naaldwijk have evaluated the prototype, together with the project team members working for Koppert BV. Five growers of three crops (pepper, tomato, cucumber) have been selected to evaluate the prototype. Participants carried no risk, since the programme did not really interfere with the day-to-day management. During programme testing growers still made theri own decisions on crop protection measures, and only used the advice database as a confirmation (or 'de'-firmation).

Development of quantitative monitoring methods was done alongside programme design. Therefore methods could not be evaluated before building them into the programme. Maximum input of biologicals was the background of advice database. This did not always correspond with growers' decisions at the time of the evaluation. By now this is already changing.

It is expected that successful implementation of the decision support system will predominantly depend on growers' intentions to optimize the use of beneficials. Currently, there seems to be little incentive to change standard operating procedures regarding biologicals. More research effort is needed to find out how to bridge the gap between current and desirable use of beneficials by growers.

DEVELOPMENT OF IPM ON PROTECTED AUBERGINE

J. A. Bennison[1] , C. Sampson[2,3] , A. Vautier[2] and P. F. Challinor[2]
[1] ADAS Cambridge, Brooklands Avenue, Cambridge CB2 2BL, UK.
[2] Department of Agriculture and Fisheries, PO Box No 327, Howard Davis Farm, Trinity, Jersey, JE4 8UF, Channel Islands.
[3] Ciba Bunting Ltd, Westwood Park, Little Horkesley, Colchester, Essex, CO6 4BS, UK.

Abstract
A crop of aubergines was grown during 1994/95 in an experimental glasshouse at Howard Davis Farm, Jersey, using an IPM programme aimed to maximise use of biological pest control and minimise pesticide input. Glasshouse whitefly and onion thrips were well controlled by *Encarsia formosa* and *Amblyseius cucumeris* respectively. Spider mites were well controlled, particularly by *Therodiplosis persicae*, with a contribution by *Phytoseiulus persimilis* and one spot treatment with fenbutatin oxide. Aphid species were well controlled by a combination of *Aphelinus abdominalis*, *Aphidius colemani* and *Aphidoletes aphidimyza*, with only one spot treatment of nicotine used to reduce damage by *Aulacorthum solani*.

Introduction
Aubergines are a good host for many pest species and severe damage can rapidly occur if effective control is not maintained. In a crop grown under IPM at Howard Davis Farm during 1993/94, glasshouse whitefly, *Trialeurodes vaporariorum*, was well controlled by *Encarsia formosa*, onion thrips, *Thrips tabaci* by *Amblyseius cucumeris* and caterpillar spp. by *Bacillus thuringiensis*. However, repeated pesticide intervention was necessary to supplement control of spider mites (*Tetranychus urticae* and *T. cinnabarinus*) by *Phytoseiulus persimilis* and for effective control of aphids (*Myzus persicae* and *Macrosiphum euphorbiae*); (Treanor, unpublished data).

The trial in 1994/95 included additional biological control agents to avoid the need for pesticide intervention. The predatory midge *Therodiplosis persicae* was first shown to be effective against spider mites on tomato in the UK in 1988 (Wardlow and Tobin, 1990). Since then, limited supplies of the predator have been commercially available in the UK, but difficulties in production prevented it from being widely available until 1995.

The main aphid species damaging aubergines are *M. persicae*, *M. euphorbiae* and *Aulacorthum solani*. *Aphidius colemani* is an effective parasitoid against *M. persicae* (van Steenis, 1993) and is now widely used against both this species and *Aphis gossypii* on protected sweet peppers and ornamentals. However, this parasitoid is reported to be ineffective against *M. euphorbiae* (van Steenis, 1993) and has not been observed parasitising *A. solani*. *Aphelinus abdominalis* is now commercially available for use against both *M. euphorbiae* and *A. solani* and the predatory midge *Aphidoletes aphidimyza* is widely available for use against all aphid species.

Materials and Methods
Cultural details
Only one glasshouse compartment of 154m^2 was available for growing aubergines, therefore only one, unreplicated IPM programme could be evaluated. The crop was planted in rockwool in December 1994 and was removed on 1 October 1995. There were a total of 408 plants, including three varieties:- Lunar, Rijk Zwaan; Ritmo (1015), Rijk Zwaan; 820,Bruinsma.

Table 1 - Biological control programme

Pest	Biological control agent	Rate introduced/timing
T. vaporariorum	*Encarsia formosa*	10/m^2/wk
Tetranychus urticae/cinnabarinus	*Phytoseiulus persimilis*	13/m^2, on 25 May and 22 June
"	*Therodiplosis persicae*	1.5/m^2/wk, 19 May - 22 June
Thrips tabaci	*Amblyseius cucumeris*	1 CRS sachet per 2 plants, every 6 weeks from planting
Myzus persicae	*Aphidius colemani*	0.25/m^2/wk from late January until aphids seen, then 0.5/m^2/wk
A. solani/ M. euphorbiae	*Aphelinus abdominalis*	As for *A. colemani*
All aphid species	*Aphidoletes aphidimyza*	6/m^2/wk, 11 May - 21 Sep
Caterpillars	*Bacillus thuringiensis*	Spot treatment, as required

N.B. Introduction rates were partially determined by the minimum order available from the supplier and thus tended to be on the generous side. Precise numbers of aphid parasitoids were introduced by counting out 'mummies', allowing for the small percentage expected not to hatch, estimated from the supplier's quality control tests.

Assessments
Weekly assessments were made on a top, middle and lower leaf from eight plants (one per row), giving a total of 24 leaves per week. At first, plants to be assessed were chosen at random, but from 23 June, pest - infested plants were selected, to ensure that success of biological control could be evaluated. Records were made of numbers, life stage and species of pests and natural enemies present and severity of pest damage.

Results and Discussion
A summary of pest and natural enemy assessments is given in Table 2.

It should be noted that the data given in Table 2 does not give a true representation of the biological interactions observed in the whole crop, as pest infestation was patchy and all pest species did not always occur on assessment plants. The discussion below includes weekly observations made from walking the whole crop.

Control of whiteflies: As in the previous year's trial, control by *E. formosa* was excellent. No whiteflies or black scales were recorded; it is assumed that any young scales which may have developed were killed by host feeding.

Control of spider mites: *T. urticae* were first detected on 18 May and a small patch of plants had become severely damaged by 16 June, by which time *T. cinnabarinus* was the predominant species. *P. persimilis* were detected from 26 May but were not well established until late June. *T. persicae* were detected as cocoons or larvae on infested leaves from 16 June and reached a peak of eight larvae and 31 cocoons per leaf on 30 June; the maximum numbers recorded on a single leaf were 47 larvae and 183 cocoons. A spot treatment of fenbutatin oxide was applied to the top 30cm of two severely damaged plants on 16 June, partly to reduce further damage to the growing points and partly to assess any side effects on *T. persicae.* The day after treatment, 50% spider mites were killed, but there was no apparent mortality of *T. persicae* larvae on the leaves or within cocoons. One week after treatment, further *T. persicae* were readily colonising treated leaves. From early July, the spider mites were under control, largely by *T. persicae.* New growth of infested plants was undamaged and any new patches of damage in the glasshouse were rapidly colonised by *T. persicae* and spider mites effectively controlled.

Although indigenous to Jersey, this was the first year *T. persicae* were introduced to the island. The predator, available from two UK suppliers, also gave good control of spider mites on commercial crops of tomatoes and sweet peppers (Bennison, unpublished data).

Control of thrips: *T. tabaci* were not detected on blue sticky traps or plants until late June. Numbers remained very low throughout the season and only occasional slight leaf damage recorded. Establishment and control by *A. cucumeris* was excellent.

Control of aphids: The first aphids detected were *A. solani*, causing severe damage to a small patch of plants on 25 April. Parasitism by *A. abdominalis* was already occurring; an interesting phenomenon was the presence of many of the black 'mummies' congregated at leaf nodes and under the string twisted round the stems, indicating that the aphids were trying to escape parasitism. However, by 6 May, aphid infestation was spreading rapidly and a spot treatment with liquid nicotine was used to prevent further severe damage. *A. aphidimyza* was introduced from 11 May to supplement control by parasitoids, and thereafter, the combination of natural enemies maintained excellent aphid control. *M. persicae* was effectively controlled throughout the season, mainly by *A. colemani* but parasitism by *A. abdominalis* was also recorded. Only the occasional *M. euphorbiae* was detected, parasitised by *A. abdominalis.* A small patch of *Aphis fabae* occurred towards the end of the season. No parasitism of this species occurred and *A. aphidimyza* were deterred by ants, although no severe damage occurred.

Control of caterpillars: Small patches of damage at the end of the season were effectively controlled with spot applications of *B. thuringiensis.*

Key to table 2

T.u. & T.c. = T.urticae & T.cinnabarinus
P.p. = P. persimilis
T.p. = T. persicae larvae + cocoons
T.t. = T. tabaci
A.c. = A. cucumeris

M.p. = M. persicae
A.col. = A. colemani
A.sol. = A. solani
A.ab. = A. abdominalis
A.aph. = A. aphidimyza

Table 2 - Mean numbers of pests and natural enemies per 24 leaves

Date	*T.u.& T.c.*	*P.p.*	*T.p.*	*T.t.*	*A.cuc*	*M.p.*	*A.col*	*A.sol.*	*A.ab.*	*A.aph*
25.4								x	x	
6.5								x		
12.5										
18.5	x				x	x	x			
26.5	x	x					x		x	
2.6	x					x	x		x	x
9.6	x						x			x
16.6	x		x	x	x	x	x		x	
23.6	879	9	60+46	1	55	2	2	0	0	0
30.6	205	49	61+246	9	61	3	3	0	0	0
7.7	34	29	6+163	3	66	5	12	0	4	0
14.7	0	0	0+0	1	0	9	4	0	0	2
21.7	0	1	0+3	6	39	2	5	6	0	0
27.7	0	0	0+0	9	23	4	2	0	0	0
4.8	0	0	0+0	4	64	5	4	0	2	7
11.8	1	0	0+0	13	18	15	7	1	4	0
25.8	0	0	0+2	58	77	1	4	0	0	0
1.9	0	0	0+4	32	45	0	3	4	1	0
8.9	25	0	0+0	5	90	0	8	0	1	0
15.9	24	0	1+0	10	38	1	3	0	0	0
22.9	1	0	0+0	1	22	0	7	0	2	0
27.9	0	1	0+0	4	29	6	14	0	2	0

x = Recorded in crop but not on assessment plants and therefore not counted

Conclusions

All major pests of aubergine were successfully controlled by natural enemies, with minimal use of pesticides. Of particular interest was the successful control of spider mites by *T. persicae* and control of aphids by a combination of *A. abdominalis*, *A. colemani* and *A. aphidimyza.* Due to the rapid severe damage caused by *A. solani*, higher preventive rates of introduction may be needed to avoid intervention with an aphicide. Reduction in the rates of other natural enemies used in this trial would be worth evaluating, to make IPM more cost-effective.

Acknowledgements

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STATE OF THE ART AND THE FUTURE OF IPM IN GREENHOUSE VEGETABLES IN ISRAEL

Berlinger M.J., Sarah Lebiush-Mordechi, J. Rosenfeld

Entomology Laboratory, ARO, Gilat Regional Experiment Station,
Mobile Post Negev 85-280, Israel

Summary

In warm countries pests develop outdoors during summer and migrate into greenhouses once the open field crops are harvested in autumn. This migration is the main source of primary greenhouse infestation by pests. A three phase IPM strategy has been developed to control the invasion, establishment and damage of the pests in greenhouses: (1) Mechanical barriers - screening greenhouses to physically exclude insects. This is in many cases an efficient control measure by itself. (2) Biological control - introducing "beneficials" to control any insect population which has invaded the greenhouse despite the exclusion screens. (3) Complementary control - using environmentally safe pesticides (Oils, soaps, detergents, etc.) as needed if the pest population is not controlled efficiently by the two methods mentioned above.

Introduction

Vegetables are grown year round in many warm countries. In summer they are grown outdoors and in winter in greenhouses. Indoor crops are generally planted in September and harvested until May or June. Whiteflies and other pests take off in large numbers when the outdoor crops are harvested (September-October) and disperse in search of new host plants. During this dispersal flight they penetrate greenhouses, attack the newly planted crops and establish patchily distributed indoor colonies (Berlinger et al. 1983, Berlinger et al. 1988). From these foci a rapid population build up resumes in spring.

Vegetables, mainly tomatoes, have been cultivated in Israel in greenhouses since the late 70's. Pest problems increased very rapidly. Within a few years the tomato yellow leaf curl virus (TYLCV) became the limiting factor of tomato production. This virus is spread solely by the tobacco (sweetpotato) whitefly, *Bemisia tabaci*, in a semi-persistent way. A viruliferous whitefly infects a healthy plant within a few hours of feeding (Berlinger et al. 1990). The only applicable way to prevent the virus transmission today is by preventing the whitefly from feeding on a healthy plant more than the time needed to infect the plant. In the late 70's some of the pyrethroid insecticides were proven to effectively prevent TYLCV transmission. After just a few years, by the early 80's, the efficacy of those pyrethroides decreased drastically and growers reacted by spraying their crops daily and in some cases even twice a day in order to save their yield. Such a heavy spraying schedule soon became uneconomical in addition to all the other well known shortcomings of the use of insecticides. This situation called for alternative methods to combat the whiteflies and the TYLCV.

The IPM Strategy

Based on our investigations on the flight activity and behavior of the whitefly in space and time, a three phase IPM strategy has been developed to control the invasion, establishment and damage of the pests in greenhouses:

Phase 1. Mechanical barriers - screening greenhouses to physically exclude insects. This is in many cases an efficient control measure by itself.

Phase 2. Biological control - introducing "beneficials" to control any insect population which has invaded the greenhouse despite the screens.

Phase 3. Complementary control - using environmentally safe pesticides (Oils, soaps, detergents, etc.) as needed if the pest population is not controlled efficiently by the two methods mentioned above.

Methods and Materials

Numbers of weekly trapped insects and the incidence of TYLCV infected tomato plants were used to indicate the efficacy of the examined control measure. Virus infected plants were determined according to visual symptoms. Various insects were monitored by yellow sticky traps. A disposable Petri dish 9 cm in diameter, was smeared inside with an insect glue and exposed horizontally on a yellow corrugated board for weekly intervals. Greenhouses were screened and had double doorways to prevent insect infiltration.

Results

First phase: Mechanical control - the use of exclusion screens

Experiments with a variety of screens were performed in close cooperation with the growers, extension services and industry. The results led to the development of a range of whitefly proof screen, specified by combinations of 0.20-0.22 mm thread thickness woven at densities of 25-28 x 50-58 threads/inch (Berlinger et al. 1991, Zipori et al., 1988,). The screens must be applied before planting and fixed thoroughly to prevent even the smallest opening. In cases where the forced-ventilation of the greenhouses was needed, it was done carefully without increasing the pests' influx (Berlinger and Lebiush-Mordechi, 1996).

In commercial greenhouses the screens exclude whiteflies in an economically satisfying way (Fig. 1A), keeping TYLCV incidence well bellow the economic threshold of 10% infected plants at the end of the growth season. The screens also effectively excluded other insects equal or greater in size than whiteflies e.g. aphids and leafminers (Figs. 1B, 1C).

It is the wide spread acceptance of the economic use of screening which has allowed us to move on to the next phases of the IPM program.

Second phase: Biological control

Biocontrol should be the preferred measure to control the pests which have invaded greenhouses in autumn despite the screening (Fig. 2). The pests, which survive winter indoors, will increase very rapidly in spring and (Berlinger et al. 1988) and therefore must be controlled. We have started to investigate the local fauna of beneficials in order to select a preferred parasite or predator, to check the correct timing of the beneficial's releases before or after winter, and to look for the economic threshold of pest population densities. The size of the plants in spring and the rapid increase in the pest populations, makes correct timing of control applications very difficult. Whenever direct counts or trapping of pests failed to anticipate the pest population explosion, "indicator plants" were used to predict the pest population and to improve the timing of the introduction of the beneficials (Berlinger at al. 1996).

Third phase: Complementary control

When biocontrol agents are not available, as for the tomato russet mite, or ineffective, as with the tobacco whitefly, complimentary means must be applied. Weekly sprays of a light summer oil efficiently controlled whitefly larvae as well as the tomato russet mite populations. These applications did not interfere with the activity of the bumble bee pollination.

Fig. 1: Occurence of trapped insect-pests in a screened Greenhouse vs. outdoors

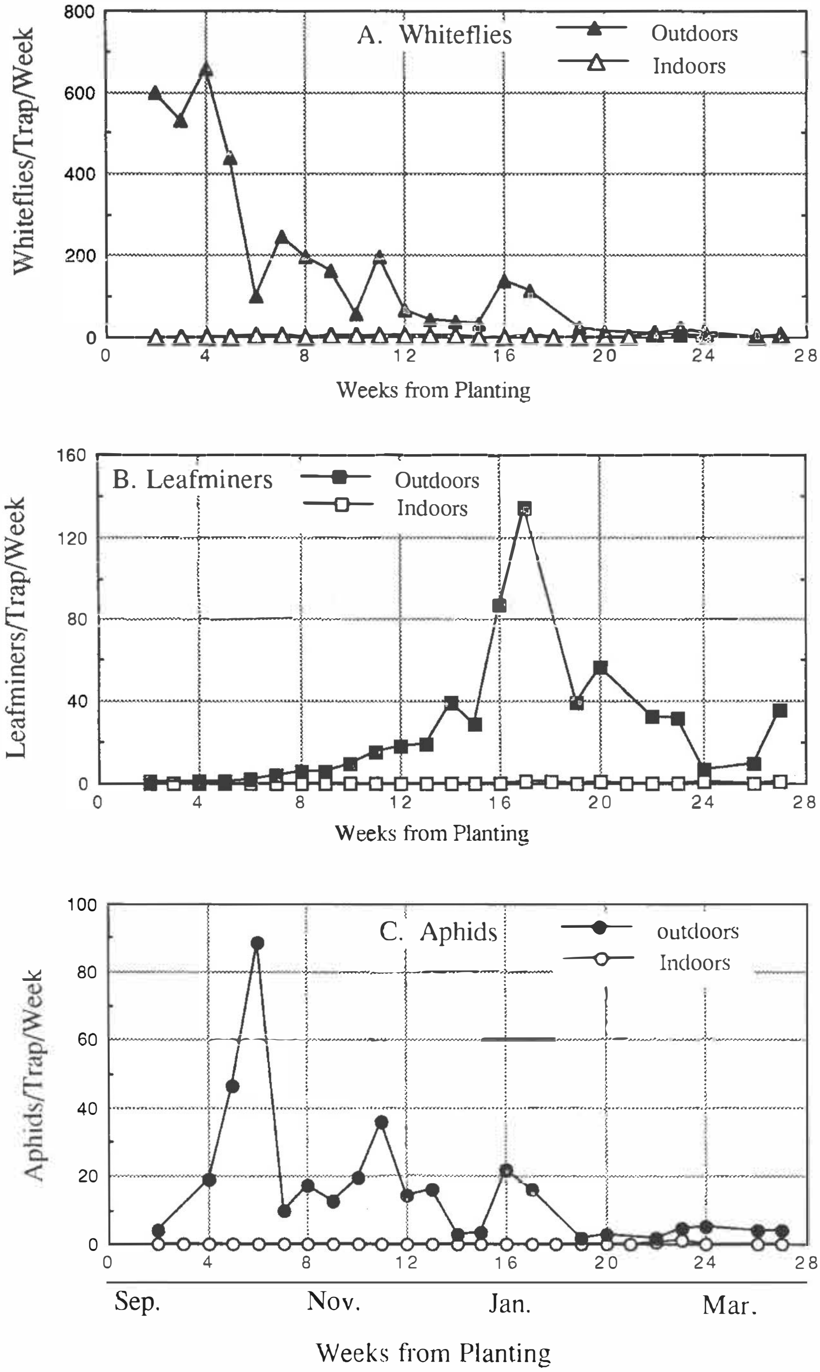
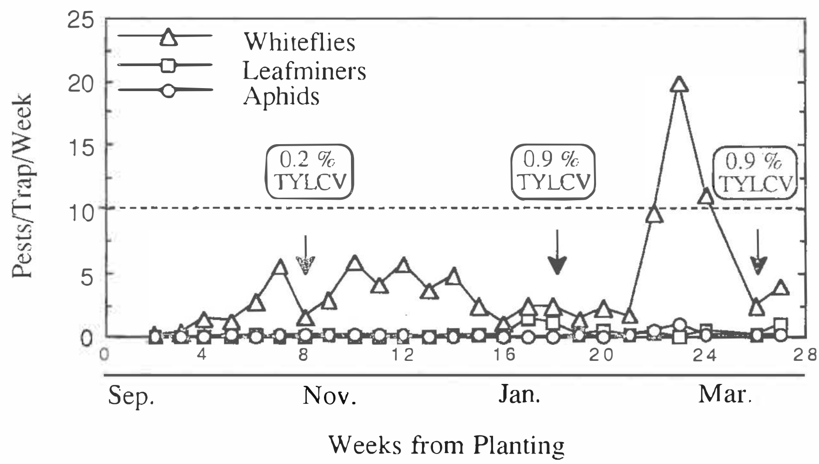


Fig 2: Occurence of trapped pests in a tomato greenhouse crop and the incidence of TYLCV. (---- Whitefly Economic Injury Level)



In conclusion

Screening greenhouses with a suitable insect-proof screen minimizes pest immigration, significantly reduces insecticide applications, provides the basis for the implementation of an IPM program, and enables the use of bumble bee pollinators. Consequently all greenhouse tomatoes and many other greenhouse crops are protected by screens today.

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EFFECT OF SELECTED MASS-REARING PARAMETERS ON *O. MAJUSCULUS* (REUTER) AND *O. LAEVIGATUS* (FIEBER)

S. Blümel,
BFL, Institut für Phytomedizin, Spargelfeldstr. 191, A-1226 Wien

Summary
O. majusculus and *O. laevigatus* were mass-reared at 25 + 2°C, 70+/-10% relative humidity and 16h photoperiod in polypropylen-boxes filled with corrugated board scrapes and the provision of drinking water. *Ephestia kühniella* eggs served as food and Cyclamen-leaves as oviposition substrate. Egg-hatching rates, sex-ratio, food-requirements, the influence of rearing-density on the yield and the effect of cold-storage on the survival rate of adults were compared for both species.

Introduction

Predatory bugs from the genus *Orius* (Heteroptera: Anthocoridae) are considered as effective biological control agents of phytophagous thrips on greenhouse crops. *O. majusculus* and *O. laevigatus* are described both to be efficient predators of thrips and to be frequently present on a variety of vegetable and ornamental crops (Ruidavets, 1995). For both *Orius*-species different parameters and methods for mass-production were investigated (Alauzet et al., 1992 and 1994; Rudolf, et al., 1993; Tommasini & Nicoli, 1993). From 1993-1995 trials to develope a mass-rearing method for *O. majusculus* were carried out at the BFL, Vienna. *O. laevigatus* was included in the studies, when the influence of the photoperiod on the induction of diapause in different *Orius*-species was detected (van den Meiracker, 1994).

Material and methods

Rearings were carried out in 2,75l polypropylen-boxes, which were filled with corrugated board scrapes as rearing substrate, with a layer of kleenex on top. The boxes were placed in containers of the same size, serving as water reservoirs. Filter paper strips leading from two rims of the inner box to the water supply in the outer box were used as drinking device for the predatory bugs. The inner box was closed on top by a lid with air-openings, which were covered by gauze to prevent the predators from escaping of the box. As food source served deep-frozen and rethawned *Ephestia kühniella* eggs, which were distributed over the kleenex layer. Food was added every two or three days, like the Cyclamen-leaves, which were offered as egg-laying substrate. Rearing units were kept in a climatic chamber at 25 + 2°C, 70+/-10% relative humidity and 16h photoperiod. From day eleven until day eighteen after the incubation of the eggs the different developmental stages of the predatory bugs were harvested. Adults or last instar larvae were collected in a combined process of sieving the rearing substrate containing the cold-paralysed *Orius* and by sucking them up with a suction sampler. The harvested bugs were stored at 9°C continuous temperature and 75%-90% relative humidity in a commercial refrigator. 500 ml polyethylen plastic bottles with air-inlet and filled with humid vermiculit served as storage containers, which were also used for the distribution of the predators in the greenhouse. The following parameters were investigated:

- egg-hatching-rates

- influence of different population densities in the rearing boxes on harvest
- sex- ratio
- food-requirements
- influence of cold-storage on survival and on food quality

Trial data derived from continuous mass-rearing of *O. majusculus* over a period of 70 weeks (170.000 individuals) and of O. *laevigatus* over a period of 56 weeks (94.000 individuals).

Results

The choice of the rearing substrate resulted from trials with *O. majusculus*, in which the suitability of barley grains, kleenex, vermiculit with different degree of humidity and of grain size and corrugated board scrapes were examined. Corrugated board scrapes and coarse, dry vermiculit produced the highest yields with 53%- to 60% adult harvest from the original number of eggs incubated. The first substrate was chosen as standard, because it was easier to handle during the rearing and harvesting process. The maximum yield per week was about 15000 individuals. The egg-hatching rate on an average ranged from 76,4 ± 9,7 % for *O. majusculus* to 86,9 ± 3,3 % for *O. laevigatus*.

The optimal number of eggs per rearing box to achieve a maximum harvest of adult or last instar larvae of both *Orius* -species resulted in higher output for *O. majusculus* in the class up to 500 eggs per rearing box, whereas for *O. laevigatus* higher yields were obtained from boxes with more than 500 eggs.

Tab. 1: Percentage yield of *Orius sp.* at different rearing densities (means ± SE)

	number of eggs per rearing box			
Orius-species	0-500	500-1000	>1000	average
O. majusculus adults	64,5 ± 2,3%	54,3 ± 1,8%	53,8 ± 1,1%	54,8 ± 1,7%
O. majusculus larvae	72,9 ± 0,5%	53,6 ± 1,7%	50,4 ± 0,5%	53,9 ± 1,6%
O. laevigatus adults	31,9 ± 5,2%	60,5 ± 3,8%	56,0 ± 3,4%	51,8 ± 5,3%
O. laevigatus larvae	52,8 ± 0,6%	57,8 ± 3,3%	53,1 ± 2,0%	54,9 ± 2,5%

The mean sex-ratio found for both species was 52% females to 48% males.

As standard amount of food 210 *Ephestia*-eggs per *Orius* were fed during the development from egg to adult. In feeding trials the reduced quantity of 120-140 *Ephestia* eggs *Orius* resulted in a maximum yield decrease of 4,2% (tab. 2).

Tab. 2: Yield of *Orius sp.* in % of incubated eggs at different quantity of food offered (means ± SE)

	amount of Ephestia-eggs in % of standard quantity		
Orius-species	50-75%	75-100%	>100%
O. majusculus adults	58,8 ± 2,4%	54,5 ± 1,6%	not offered
O. majusculus larvae	64,3 ± 2,0%	49,8 ± 0,9%	not offered
O. laevigatus adults	49,6 ± 2,5%	56,3 ± 5,2%	31,4 ± 4,0%
O. laevigatus larvae	49,7 ± 1,9%	61,8 ± 0,7%	69,8 ± 1,9%

Egg- production was checked weekly over a period of four weeks. Females of both species layed about 80% of the total amount of eggs during the first two weeks (tab.3).

Tab. 3: Egg-production in % of total number of eggs (means ± SE)

species	week 1	week 2	week 3	week 4
O. majusculus	51,1 ± 15,5%	34,1 ± 10,6%	13,1 ± 6,5%	0,9 ± 1,6%
O. laevigatus	42,2 ± 6,3%	35,7 ± 1,3%	14,2 ± 3,5%	7,9 ± 1,4%

In pre-studies with *O. majusculus*, including a variety of different storage substrates like wheat bran, corrugated board and various granulation types of vermiculit, a preparation of humid, fine-granuled vermiculit resulted in the highest survival rates of the test animals. The duration of cold-storage reduced the survival rate of *O. laevigatus* adults and larvae more than that of *O. majusculus* adults. Whereas for both species a one week cold storage period resulted in a survival of 80-95%, mortality increased to more than 40% in *O. laevigatus* after two weeks cold storage and to more than 50% for *O. majusculus* after three weeks cold storage. Reduction was up to 2 times higher for males than for females (tab.4).

Tab. 4: Mortality rate of *Orius* adults and larvae in % after cold storage
at 9°C, 75-90% relative humidity

	Duration of cold storage in weeks		
Species/ develop. stage	1 week	2 weeks	3 weeks
O. majusculus adults	17,6%	17,9%	57,9%
females	11%	7,3%	38,5%
males	26,5%	29,8%	80,5%
O. laevigatus adults	5,6%	41,6%	92,6%
larvae	21,6%	44,5%	not checked

Cold storage of *O. majusculus* females reduced egg-production compared to the quantity layed by unstored females with increasing storage duration. The number of eggs decreased by 6,3% after one week cold storage and by 59% after two weeks, however only by 38% after three weeks. The quality of deep-frozen *Ephestia*-eggs as food was also affected by the duration of cold-storage. Ten weeks storage reduced the harvest of adult *O. majusculus* by 2%, and by 26% after twenty weeks.

Discussion

The described rearing method proved to be suitable for a mass production of *O. majusculus* and *O. laevigatus*. More favourable results than those presented by Alauzet (1992) and Tommasini & Nicoli (1993) were obtained for the yield of adults which was on the average 14% higher for *O. majusculus* and 30% higher for *O. laevigatus*. Furthermore 13,5% more females were detected in *O. laevigatus* samples and 32% less food was required to achieve

the same average yield of 52% *O. laevigatus* than stated by Tommasini & Nicoli (1993) for a yield of 28%. These differences in the rearing results might be due to the different number of test animals checked during the trials and to the improvement of rearing conditions by provision of additional drinking water and of corrugated board scrapes as shelter. Temporal distribution of egg-production in *O. laevigatus* at 25°C differed from the results of Alauzet et al. (1994) as the main part of eggs was already layed within the first two weeks of the egg-laying period, which is two weeks less than described by the quoted authors. The data presented by Rudolf et al. (1993), about the influence of cold-storage on *O. majusculus* and *O. laevigatus* adults, show distinctly higher survival rates, higher longevity and higher egg production of both species after cold-storage at 9°C. These differences could be explained by the provision of fresh leaf material and nutrition by the authors at regular intervals during the storage period, as well as by the lower trial temperature of 22 °C for the observations after the storage period in contrast to 25°C used in the present trials. Very similar results were found for the percentage of egg-hatching and the different developmental time of both species (for which data of own trials were not included in this paper), as described by Alauzet (1992), Tommasini & Nicoli (1993) and Alauzet et al. (1994).
Although the described rearing-method offers promising possibilities for mass-production of *O. majusculus* and *O. laevigatus*, and it is considered as economically rather feasible, improvements in cold-storage and cost reductions in regard to the factors food and harvest would be favourable.

Acknowledgement
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CURRENT STATUS OF IPM IN GREENHOUSES IN AUSTRIA

S. Blümel & P. Schausberger,
BFL, Institut für Phytomedizin, Spargelfeldstr. 191, A-1226 Wien, Austria

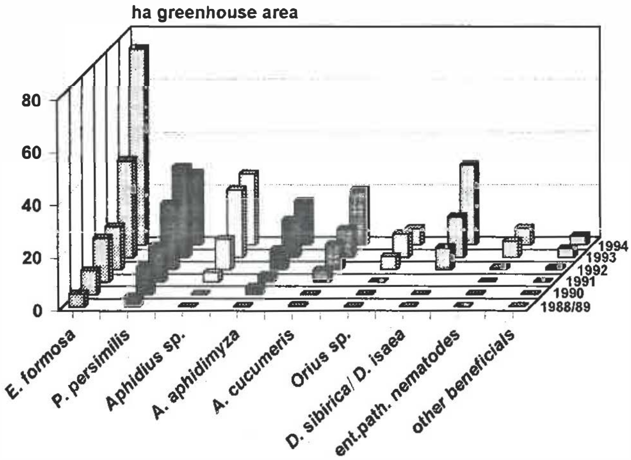
Summary
In 1994 up to 17 different beneficial organisms were applied on more than 200 ha of greenhouse crops in Austria. Key factors influencing the use of beneficials are legislation and an advisory service for the implementation of IPM into horticultural production. Research activities concentrated on trials about aphid and thrips control in greenhouse cut roses.

Legislation
In the revised version of the Federal Act about the Transactions with Plant Protection Products in Austria dated from 1990 naturally occurring organisms, microorganisms and viruses are regarded as active substances of plant protection products. The authorization of plant protection products is regulated by the Plant Protection Products Act (1990), the Act on Genetic Engineering (1995) and in future by the Convention on Biological Diversity (1993). In the authorization process the Federal Ministry of Agriculture and Forestry, the Federal Ministery of Health and Consumer Protection and the Federal Ministry of Environment are involved. The use of plant protection products can be affected by acts on county level, the Chemicals Act (1988) (for inerts) and in future by the FAO-Code of Conduct for the Import and the Release of Exotic Biological Control Agents. The requirements for the approval of organisms or viruses as plant protection products, which have to be fulfilled and for which the informations have to be submitted to the authorities, were specified in provisional form sheets for the application. Up to 17 beneficial organisms from 6 companies were approved for the use in greenhouse crops in Austria. The authorization is valid for ten years at maximum.

Development of the use of beneficials in Austria
The area of use of beneficial arthropods and entomopathogenic nematodes in greenhouse production in Austria has increased from 8,8 ha in 1989 to 212,5 ha in 1994 (fig. 1). Besides the main beneficial species other species of minor use are *Aphelinus abdominalis*, *Chrysoperla carnea*, *Cryptolaemus montrouzieri*, *Leptomastix dactylopii* and *Leptomastidea abnormis*. Entomopathogenic nematodes applied include *Heterorhabditis heliothidis*, *Steinernema carpocapsae* and *Steinernema bibionis*. Nearly half of the beneficials are released in ornamental production.

Advisory service
Advisory service is one of the key factors for the successful implementation of BC/IPM. Since spring 1992 a project on advisory service for the assistance of greenhouse growers in learning BC/IPM has been set up in Austria. The project is carried out by the Austrian Horticultural Growers Association (OGE) and funded by the Ministry of Agriculture and Forestry. In 1992 and 1993 only one, in 1994 and 1995 two full-time BC-advisers have been appointed. The growers either are visited in regular intervals of 10 to 14 days throughout the growing season or single consultations are made by appointment. The first appointment is free of charge for all horticultural growers. Each visit is recorded by the adviser, a copy of the record remains in the greenhouse.

Fig. 1: Use of beneficials in greenhouse crops in Austria



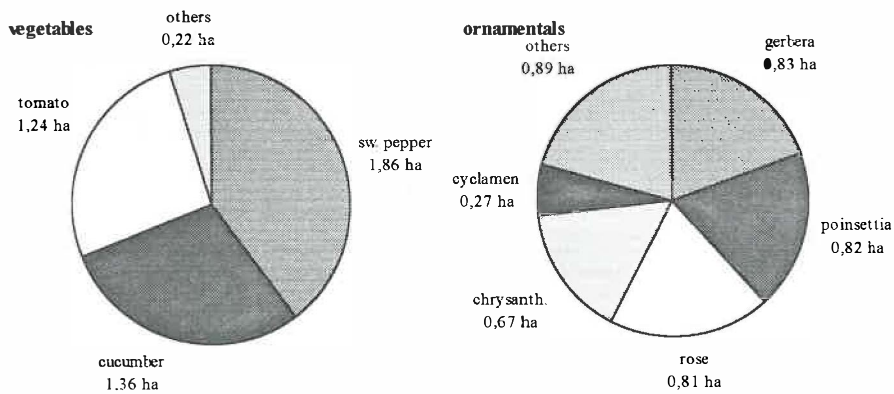
The main tasks of the advisory service are as follows:
- identification and monitoring of pests and diseases
- recommendations for biological control options (species, quantity, timing of beneficial introduction).
- information on the basic biology of the pest organisms and their biological control agents.
- guidance for handling and practical use of the beneficial organisms.
- information on accompanying biotechnical methods and the possible combined application of pesticides and their side-effects.
- monitoring the efficacy of all plant protection methods.
- on demand delivery and introduction of beneficials.

Tab. 1: Development of the Austrian BC/IPM Advisory Service from 1992 to 1995:

		1992	1993	1994	1995
No. of growers (regularly visited)		14	21	43	55
No. of consultations (altogether)		190	279	278	450
Area:	vegetables	17.100 m²	32.700 m²	46.600 m²	46.700 m²
	ornamentals	12.700 m²	9.600 m²	25.500 m²	43.900 m²
	complete	29.800 m²	42.300 m²	72.100 m²	90.600 m²

According to the monitored area the growers have to pay for the consultations (except for the first one), but the charges are rather small. In financial respect it is an urgent target for the future to cover at least one third of the costs by the growers, but at the same time this is one of the main problems for the extension of the advisory service. Since Austria has become a member of the EC the growers have to adapt to a new market-situation. A currently decreasing income reduces their intention to apply beneficials and to pay additionally for an IPM advisory service. The BC/IPM advisers monitor on an average 1500 to 2000 m² horticultural area per grower. In 1995 55 growers have been consulted in regular intervals (in a range of 2 to 30 consultations per grower per year).

Fig. 2: Crops monitored regularly by the BC/IPM Advisory Service in 1995



In addition to the consultation-activity the advisers give lectures and training courses to acquaint new growers with the methods of BC/IPM. They organize group meetings in commercial greenhouses to show the beneficial organisms in practice and they present and distribute specific informations at horticultural fairs and exhibitions. Series of articles are currently published in Austrian horticultural journals. In cooperation with experts of the Federal Office and Research Centre of Agriculture, Department of Phytomedicine specific IPM manuals have been written and are available for the following crops: cucumber, sweet pepper, tomato, gerbera, rose, chrysanthemum and poinsettia. The manuals provide detailed recommendations for the use of biocontrol agents and the proper application of integrated pesticides and their side-effects. They give informations on greenhouse hygiene and the optimal cultural practices to reduce disease incidence.

Future prospects:
At the moment the advisers are placed in Vienna, a lot of time has to be spent by travelling to the growers in the districts. It is an urgent need to decentralize the BC/IPM Advisory Service with the objective to get at least 4 operating stations in Austria. To minimize the costs and to maximize the benefits to the growers probably an advisers-association for BC/IPM will be founded in the near future. Due to promising results in 1995, the BC/IPM Advisory Service will make efforts to extense its activities and to establish biologial control on green plants in public buildings.

Research topics

The main project from 1988-1992 was the cooperation with the Austrian Horticultural Association in building up a mass rearing facility for beneficial arthropods in Austria. At the

same time training courses for growers and students as well as information of the public were of major concern. From 1991-1993 investigations on the biological or integrated control of aphids on greenhouse cut roses and from 1991 -1995 for the biological control of thrips on this ornamental crop were carried out..
For the control of *Macrosiphum euphorbiae,* an important and predominant aphid species on greenhouse cut roses in Austria , with the the parasitoid *Aphelinus abdominalis*, trials took place in the rose varieties Frisco, Kardinal and Vivaldi at a commercial producer on a greenhouse area of 630 m^2 to 700m^2 . Other plant protection measures necessary against spider mites or powdery mildew involved other beneficials or selective chemical treatment. Both the inundative release of 9,6 *A. abdominalis*/m^2 in total from 10 release points and the release of 2,2 *A. abdominalis*/m^2 in total from 2 release points within an open rearing system, were investigated and the percentage of infested rose shoots in combination with the degree of infestation were evaluated. The results showed that an effective reduction of present or newly developing aphid populations down to 0% infestation of rose shoots with aphids was possible for several weeks under the conditions of a commercial greenhouse production. Up to 68% parasitized aphid mummies were found on the rose variety Frisco. Other natural enemies of aphids like *Aphidoletes aphidimyza*, which were released or like syrphids which were naturally occurring were only rarely found aggregated on few rose plants. Up to two additional treatments against the aphids with the selective insecticide pirimicarb had to be applied, especially because the second most present aphid species *Rhodobium porosum* was not parasitized by *A. abdominalis.* The amount of insecticides used against aphids declined to 25% in comparison to greenhouses were only chemical pest control was carried out. The suitability of the different introduction methods of *A. abdominalis* for the control of aphids on greenhouse cut roses seems to favour the open-rearing system, because it better guarantees overlapping generations of the parasitoid in the greenhouse,and a synchronisation in the presence of host aphids and parasitoids in an commercial cut rose production and because of economic reasons. The use of *Chrysoperla carnea* eggs and larvae and of *Verticillium lecanii* against aphids on cut roses were not effective or resulted in problems with the application. For the control of phytophagous thrips like *Frankliniella occidentalis* on greenhouse roses, the predatory mite *A. cucumeris* and the predatory bug *Orius majusculus* were tested at various infestation levels, on different rose varieties and with different introduction methods. For evaluations blue sticky traps as well as the rose flowers were controlled. Neither the direct application of *A. cucumeris* in regular intervals, nor the slow release system or the release of different developmental stages of *O. majusculus* led to an effective and lasting reduction of the thrips infestation.

Future aspects
During the next years a project will be started to encourage growers to increase the use of biological control in cucumber production. Furthermore *A. californicus* will be tested for spider mite control in different crops in comparison to *P. persimilis* and trials will be carried out to find ways to cope with thrips on greenhouse ornamentals.

Acknowledgement
We gratefully acknowledge the provision of informations by A. Ambrosch from the advisory service of OGE-BIOHELP.

PREY PREFERENCE OF *HYPOASPIS MILES* (BERLESE) (ACARINA: HYPOASPIDIDAE): NON-INTERFERENCE WITH OTHER BENEFICIALS IN GLASSHOUSE CROPS

H.F. BRØDSGAARD, M.A. SARDAR[1] AND A. ENKEGAARD

Department of Plant Pathology and Pest Management, Danish Institute of Plant and Soil Science, Lottenborgvej 2, DK-2800 Lyngby, Denmark

Introduction

Biological control is currently being implemented into an increasing range of glasshouse cropping systems. Therefore, to enable biological control of the entire pest complex in the various glasshouse crops, the demand for additional effective biological control agents is increasing rapidly. An example of this is reports on use of soil-dwelling Hypoaspididae for control of soil pests (Gillespie and Quiring, 1990; Glockemann, 1992; Chambers *et al.* 1993). *Hypoaspis miles* (Berlese) (Acarina: Hypoaspididae) is a common inhabitant in a range of soil habitats and is capable of adapting to glasshouse conditions. Glockeman (1992) reported that *H. miles* is oligophagous feeding on different stages of thrips and possibly other prey like mites, Collembola etc. in glasshouses. Wright and Chambers (1994) reared *H. miles* on *Acarus siro* L. (Acarina: Acaridae) and called it polyphagous in relation to *H. aculeifer* Canestrini. Artificial feed has also been used for rearing of *H. miles* (Das *et al.* 1987). *H. miles* is currently commercially available from several European and American insectaries.

The interactions of this polyphagous predator with the rather complex fauna of pest species present in many glasshouse cultures and with the variety of beneficials in biological-integrated control programmes should be known. Therefore, the objectives of this study were to investigate and quantify the prey preference of *H. miles* when offered different prey relevant to the glasshouse habitat.

Materials and methods

Two-choice experiments as well as long term culture observations were conducted to investigate prey preferences of *H. miles* among nine possible glasshouse prey types including soil-dwelling stages of two beneficials. The offered prey items were mushroom sciarid larvae (*Lycoriella solani* Winnertz) (Diptera: Sciaridae), thrips pupae (*Frankliniella occidentalis* [Pergande]) (Thysanoptera: Thripidae), eggs and nymphs of *Isotomurus* sp. (Collembola: Entomobryidae), eggs and mobile stages of mould mites (*Tyrophagus putrescentiae* [Schank]) (Acarina: Acaridae), leafminer pupae (*Liriomyza bryoniae* Kalt) (Diptera: Agromyziidae), gall-midge pupae (*Aphidoletes aphidimyza* Rondani) (Diptera: Cecidomyiidae), and infective stages of entomopathogenic nematodes (*Steinernema feltiae* [Filipjev]) (Nematoda: Steinernematidae).

Prey preference of *H. miles* was studied using two-choice arena experiments with single adult female predatory mites. The arenas consisted of circular plastic containers (5 cm (∅); 7 cm (h)) with a layer of plaster of Paris and charcoal (7:1) in the bottom. A shallow circular cavity was made in the centre of the plaster of Paris layer in containers used for

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[1] Present address: *Dept. of Entomology, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh*

trials with nematode prey. To prevent mobile prey and predators from escaping, the containers were sealed with cling film secured by rubber bands. The containers were kept in climate cabinets at 20°C and a photoperiod of 16:8 (L:D) using 2 W/m^2 resulting in a light intensity of 5 μE inside the observation containers.

To facilitate quantitative comparisons, equal sized prey was preferably compared, e.g., L_2 and L_3 of sciarids were compared to P_2 of thrips, or eggs of mould mites were compared with eggs of *Isotomurus* sp.. Nine combinations of eight prey types were tested in 16 to 20 replicates. Ten prey specimens per arthropod species and 100 nematodes were used per replicate. Immobile prey was placed apart near the wall of the containers and mobile prey in the centre of the containers. The nematodes were released into the cavity. Single adult females of *H. miles*, starved for 24 hours, from a culture sustained on mould mites were released into the centre of each container with a combination of two prey species. The number of prey eaten during 24 hours was counted. To adjust for nematodes being lost due to handling or to disappearance because of nematodes infecting the second test prey species, 20 replicates of 100 nematodes, 10 sciarid larvae and no predator were tested, also in 24 hour periods, as nematode controls. Mean number of nematodes not recovered in the controls was used as correction factor in the preference experiments. Differences between prey eaten in the various two-choice experiments and within the same species in the various species combinations were compared using t-tests.

Long term prey utilisation. Small scale cultures of *H. miles* were maintained on different prey types to illustrate long term feasibility of the various prey species. The rearing conditions were the same as mentioned for the preference experiment, though the containers had a diameter of 15 cm. Survival and egglaying of *H. miles* were observed over a period of up to 18 months. Five sets of rearings were established on *L. solani*, *T. putrescentiae*, *L. bryoniae*, *A. aphidimyza*, and *S. feltiae*, respectively. Five adult mated females of *H. miles* were used to start each culture. Respective prey was added to the containers in surplus numbers at four to six days' intervals with a few drops of water on the plaster-charcoal layer. Observations were made periodically to examine feeding, egg-laying and development of the predators in the culture with the various prey species.

Results

Prey preference. The results of the prey preference experiment are shown in Table 1. The preferred prey of the eight prey items tested appeared to be sciarid larvae followed by thrips pupae and *Isotomurus* sp. nymphs. There was no significant difference between preference for eggs of mould mites or *Isotomurus* sp.. The observed mite predation of sciarid larvae was significantly higher ($P<0.05$) in choice tests with nematodes than with other alternative prey. However, this is probably an artefact due to nematode infections of some of the sciarids making them more vulnerable to *H. miles'* predation.

Long term prey utilisation. *H. miles* was able to develop and reproduce on all five prey species, but the must rapid population increase was observed on sciarid larva and mould mite prey (for life table data, see Enkegaard *et al.* 1996). The population developments were slow in cultures on the other three species. When fed on leafminers and gall midges both immatures and adults developed a dark brown coloured cuticula. Observations revealed that the mites hardly were able to penetrate the chelicerae into the puparies or cocoons. For the culture on nematodes, it was observed that when too many nematodes were present in the culture, the reproduction of the mites ceased and the mites were found on the walls of the containers for most of the time resulting in an increased mite mortality.

Table 1: Mean number (S.E.) of prey eaten during 24 hours by single female *H. miles* in two-choice experiments. Differences between prey preference were tested by t-tests; ns, not significant; and nt, not tested.

Prey species		**Mean no. consumed±S.E.**		**Statistics**
Prey 1	Prey 2	Prey 1	Prey 2	*P*, replicates
L. solani larvae	*F. occidentalis* pupae	1.88±0.18	1.19±0.16	*P*<0.01, *n*=16
L. solani larvae	*L. bryoniae* pupae	1.75±0.27	0.13±0.09	*P*<0.0001, *n*=16
L. solani larvae	*A. aphidimyza* pupae	2.06±0.30	0.19±0.10	*P*<0.0001, *n*=16
L. solani larvae	*Isotomurus* sp. nymphs	2.67±0.35	1.50±0.23	*P*<0.01, *n*=20
F. occidentalis pupae	*A. aphidimyza* pupae	2.06±0.14	0.25±0.11	*P*<0.0001, *n*=16
L. bryoniae pupae	*A. aphidimyza pupae*	0.00	0.09±0.09	nt, *n*=16
T. putrescentiae eggs	*Isotomurus* sp. eggs	1.73±0.49	1.28±0.38	ns, *n*=20
L. solani larvae	*S. feltiae* infectives	2.94±0.19	25.1±2.9	nt, *n*=20
F. occidentalis pupae	*S. feltiae* infectives	1.69±0.20	29.0±2.8	nt, *n*=20

Discussion

The present results suggest that *H. miles* preferred *L. solani* to the other glasshouse prey organisms tested. However, thrips pupae and *Isotomurus* sp. nymphs were readily eaten by *H. miles*, too, whereas the soil-dwelling instars of leafminers and gall midges were hardly predated. The rates of *T. putrescentiae* and *Isotomurus* sp. egg predation were quite low in spite of their small sizes. Thus, the results confirm earlier reports that *H. miles* is a potentially important beneficial for sciarid control with a beneficial side effect on thrips and Collembola (Gillespie and Quiring, 1990; Glockemann, 1992; Chambers *et al.* 1993; Wright & Chambers, 1994).

The long term *cultures of H. miles* on *L. bryoniae* and *A. aphidimyza* survived and produced a small number of immatures that were able to complete their development. The very slow population developments were presumably due to difficulties in feeding rather than a poor nutritional quality of the puparies and cocoons of the two insects to *H. miles*. Therefore, immature *H. miles* probably relied on cluster feeding and attacks on emerging adult leafminers and gall midges. In situations with other more preferred prey available, the predation on gall midges is negligible. The present studies, thus, suggest that *H. miles* will not interfere with aphid control using *A. aphidimyza*. Furthermore, *H. miles* will not interfere with any plant living beneficials since only about six per cent of a *H. miles* population is found on spidermite infested plants in situations with absence of soil-dwelling prey (Ydergaard et al. 1996).

Geolaelps oreithyiae, closely related to *H. miles*, consumed a daily average of 23 nematodes (*Acrobeloides* sp.) (Walter and Oliver, 1989). Several other Hypoaspididae are known to predate on *S. feltiae* (Poinar, 1979; Walter, 1987). The present study suggests that *H. miles* predate this entomophagous nematode to a similar degree, even in presence of more preferred prey (sciarid larvae and thrips pupae). However, the long term prey utilisation trials suggested that *S. feltiae* is a poor food source to *H. miles*. Though predation on nematodes is quite high in the present experiments, negative interactions between *S. feltiae* and *H. miles* are probably negligible under glasshouse situations. *S. feltiae* prefers very humid to wet conditions whereas *H. miles* is unable to establish in wet growth media (Hansen 1995). Therefore, *H. miles* is a potent beneficial for soil-dwelling stages of sciarids, thrips, mites and Collembola and can be incorporated into glasshouse crops without interfering negatively with existing biological control systems.

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BINOMIAL SAMPLING OF *Aphis gossypii* GLOVER (HOMOPTERA: APHIDIDAE) INFESTING WATERMELON IN OPEN FIELD IN NORTHERN ITALY

GIOVANNI BURGIO [1], ROBERTO FERRARI[2]

[1] Centrale Ortofrutticola Cesena - Istituto Entomologia "G.Grandi", University of Bologna, via F. Re,6 -40126-Bologna, Italy

[2] Centro Agricoltura e Ambiente, Crevalcore, Bologna

Summary

Taylor's power law was employed to study the spatial distribution of *Aphis gossypii* in watermelon, in Northern Italy in order to improve sampling procedures. The aggregation index (b) showed differences between years (1993 and 1994). Binomial sampling, which correlates infestation severity to infested leaf frequency, is reported and discussed, along with problems inherent in *A. gossypii* sampling and in control methods that are linked to the peculiar aggregate type of distribution of this aphid in watermelon and the rapid development of infestations in field.

Introduction

Aphis gossypii Glover, the main pest of protected cucurbits in Italy and Northern Europe, is the key-pest of watermelon in Northern Italy; some information concerning the biological cycle and the integrated control of this pest in watermelon can be found in Ferrari & Nicoli (1994). Problems associated with the infestation dynamics of this aphid in glasshouse cucumber are discussed by Boll *et al.* (1994). The main problems emerging from the study of the infestation dynamics of *A. gossypii* are chiefly related to its high aggregation rate (Burgio *et al.*, 1994), to the high inter-glasshouse variability of the pest as well as to its rapid growth. The present study reports data collected over a two year period for *A. gossypii* in watermelon crops grown in the Po Valley in Northern Italy, its purpose being to determine viable sampling strategies for scouting and studying this aphid.

Material and methods

The samples of *A. gossypii* were taken from four watermelon plots (cultivar Asahi miyako in semiforced cultivation) of about 50 untreated plants in the Province of Bologna. Sampling was made from early May to mid-end July in 1993, and from early May to beginning-end June in 1994, the last sampling date depending on site and infestation severity. The number of aphids per leaf and their development stage were recorded weekly on 200 to 400 randomly selected leaves.

Statistical analysis

i. Spatial distribution of the aphid. The mean number of *A. gossypii* per leaf (m) and variance (s^2) were calculated for total leaves sampled per plot and per sampling date. Taylor's power law ($s^2 = am^b$) (Taylor, 1961), which describes the correlation of means to sampling variances, was employed to study the spatial distribution of *A. gossypii*, the estimates of parameters (a and b) being calculated by regression of log (s^2) over log (m) to yield: log (s^2) = log a + b log (m), where the intercept (a) is a parameter essentially dependent on sampling method and the angular coefficient (b) is defined as the index of aggregation.To calculate the optimum sample size (OSS) of *A. gossypii* for direct count, the sampling variance from Taylor's power law was introduced in Karandinos's formula (1976): $n = [Z_{\alpha/2}/d]^2\, s^2/m^2$, to generate: $n = [Z_{\alpha/2}/d]^2\, am^{b-2}$, where d is the required level of accuracy expressed as a decimal (0.2-0.3-0.5) or permitted percentage of error, and $Z_{\alpha/2}$ is the standard normal deviate; for $n > 30$ and with $\alpha = 0.05$, $Z_{\alpha/2} = 1.96$ (Karandinos, 1976).

ii. Binomial sampling of the aphid. This sampling method permits to estimate the mean density of an organism (m) on the basis of the frequency of infested organs (p). In the Gerrard & Chiang

(1970) model: $\ln(m) = \alpha + \beta \ln[-\ln(1-p)]$, where α and β are constants. This statistical regression, in the form of antilogarithm (Binns & Bostonian, 1990), yields: $m = e^{\alpha}[-\ln(1-p)]^{\beta}$.
iii. Accuracy and sample size. Various formulas may be found in the literature for calculating the variance associated with the estimation of *m* from *p* (Schaalje *et al.*, 1991). In the present study, the variance and the binomial sample size were calculated according to Gerrard & Chiang (1970) and compared with those of Nyrop & Binns (1991).

Results and discussion

Tab. 1. Coefficients from Taylor's power law calculated for A. gossypii on wat ermelon

Year	n	log a ± (s.e.)	b ± (s.e.)	r^2	P
1993	31	1.63 ±(0.06)	1.52 ±(0.05)	0.96	< 0.0001
1994	32	1.47 ± (0.08)	1.87 ± (0.07)	0.95	< 0.0001
(Common)	63	1.51 ± (0.05)	1.71 ± (0.04)	0.95	< 0.0001

The fit of Taylor's power law for watermelon in open field is shown in table 1 and figure 1. As can be noted, there is a difference in the aggregation index between 1993 (b=1.52) and 1994 (b=1.87). The results, therefore, indicate a certain variability between one year and the other with regards the aggregation index of the pest even though the parameters calculated on the overall data confirm the values reported for *A. gossypii* on other cucurbits in protected crops (Burgio *et al.*, 1994). An extensive study on the infestation variability of *A. gossypii* in glasshouse cucumber crops has been conducted by Boll *et al.* (1994). Guldemond (1993), using Taylor's law, has calculated an angular coefficient of 1.43 for *A. gossypii* on cut greenhouse-grown chrysanthemums. This latter value for b is lower than those reported in the present study and in Burgio *et al.* (1994). Though b can frequently be considered a species-specific constant (Taylor, 1961), it can vary markedly for some aphid species (Elliott & Kieckhefer, 1987). Using the parameters of Taylor's power law, the optimum sample size curves for direct counts (Fig. 2) were calculated by means of Karandinos's formula (1976). Figure 3 shows the regression calculated by Gerrard & Chiang (1970), which estimates mean aphid density per leaf (*m*) according to the incidence of infested leaves (*p*), and table 2 lists the estimated parameters.

Tab. 2 - Parameters from the regression of ln (m) on ln [- ln (p_0)] for watermelon to estimate aphid density by incidence of infestation (for the symbols, see text).

ln α (±s.e.)	β (±s.e.)	r^2	P	*avglnln*(p_0)	*mse*	$s\beta^2$	N
3.59 (0.21)	1.76 (0.09)	0.86	< 0.001	- 2.01	0.96	0.007	63

The fit of the Gerrard & Chiang (1970) regression to the data is good (r^2=0.86, P<0.001). Gerrard & Chiang's formula underestimates the variance as compared to Nyrop & Binns's. It follows then that the curves obtained for the sample size calculated on the basis of the two different variances are also different. A certain difference is also observed for the two methods as far as the optimal sample size for the binomial sampling is concerned. The values of d (error level) calculated by Nyrop & Binns (1991) are > 0.5, which is the value recommended as the acceptable efficiency threshold (Feng *et al.*, 1993; Nowierski, personal communication). The main reason for this result is the relatively large value of *mse* (residual mean squared error from the regression), as already observed by Feng *et al.* (1993). The same authors recommend a method for reducing variance in binomial sampling which consists in taking into account the frequency of tillers infested with different minimum numbers of aphids or tally threshold (T). In our case, the OSS formula according to Nyrop & Binns (1991) for binomial sampling in watermelons gave acceptable values for a very low infestation range, which suggests that when infestation density is high then sampling error is also very high. The sample size required to maintain the predetermined d level derived from Gerrard & Chiang (1970) (Fig. 4) is more realistic than the previous one, but employs a less conservative estimate of variance. By way of conclusion, it may be said that: **i.** in general, the sampling of *A. gossypii* is undoubtedly problematic given the particularly aggregate distribution pattern of this pest; moreover, the aggregation index may vary from one year to another; **ii.** sampling for direct count is accurate but requires a large number of leaves to be observed; **iii.** binomial sampling according to Gerrard & Chiang's (1970) model permits considerable time and labour saving even if the sampling error due to the estimate is in some cases high; **iv.** from a practical point of view, binomial sampling may be recommended for estimating aphid colonies in semiforced crops but not before 2 or 3 weeks have elapsed from removal of the protection tunnels. In this period, in fact, the economic threshold is so low that even the appearance of the pest makes control treatments essential. Thereafter, the progressive increase of the economic threshold (not as yet clearly defined) makes sampling viable especially when the evaluation of the profitability of a treatment or of the efficacy of natural control methods is desired.

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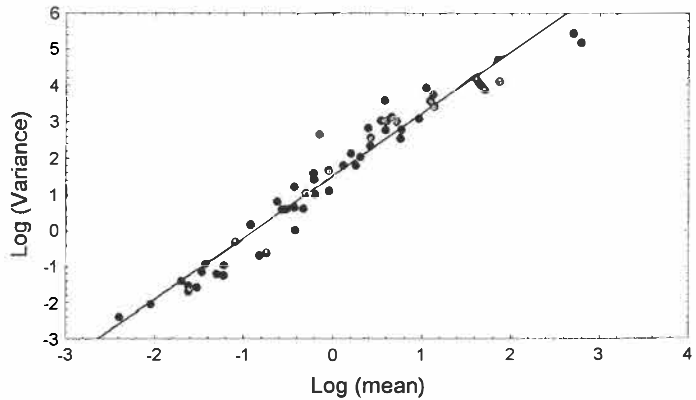

Fig.1- Taylor's power law for *A. gossypii* on watermelon (data pooled)

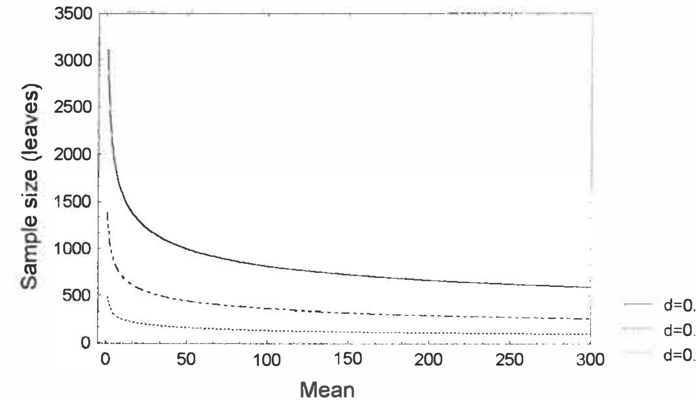

Fig. 2 - Numerical sample size curves

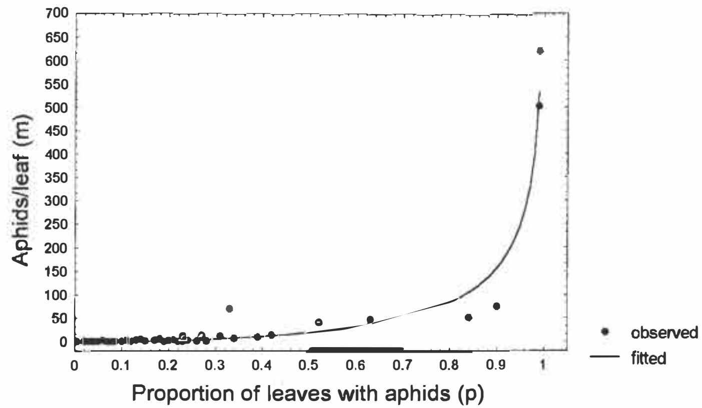

Fig. 3 - Binomial sampling according to Gerrard & Chiang's (1970) model

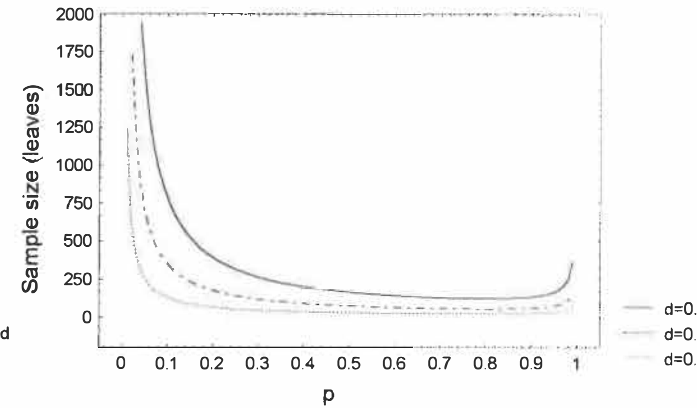

Fig. 4 - Binomial sample size according to Gerrard & Chiang (1970)

DEVELOPMENT OF CRITERIA FOR EVALUATION OF NATURAL ENEMIES IN BIOLOGICAL CONTROL: BIONOMICS OF DIFFERENT PARASITOIDS OF *BEMISIA ARGENTIFOLII*.

Y.C. Drost, A. Fadl Elmula, C.J.A.M. Posthuma-Doodeman & J.C. van Lenteren

Department of Entomology, Wageningen Agricultural University,
P.O. Box 8031 6700 EH Wageningen, The Netherlands

INTRODUCTION

Once a parasitoid fulfils the qualitative criteria that are used to identify natural enemies that have potential for biological control (van Lenteren, 1986) a selection should be made of parasitoid species that will have the greatest potential in depressing the host and, in case of inoculative releases *maintain* the host below the economic threshold density (van Lenteren, 1986; Waage and Hassel, 1986). First, one should identify those attributes that the natural enemy should possess to be effective and second one should be able to rate these attributes (Mackauer and van den Bosch (1973). Quantitative factors that are expected to determine the degree of host depression are: 1) rate of increase of the parasitoid (or a new parameter that also includes mortality due to host-feeding) as compared to the r_m of the host; 2) searching efficiency of the parasitoid at different host densities; 3) parasitoid sex-ratio; and 4) fecundity/longevity of the parasitoid. The aim of our present research is to evaluate whether any of the above criteria or a combination can be used to rank a group of selected parasitoids. The pest organism studied is *Bemisia argentifolii* Bellows & Perring, formerly referred to as *Bemisia tabaci* (Genn.) strain B or the poinsettia strain (Bellows et al., 1994). The natural enemies studied are different parasitoid species of *B. argentifolii*. For evaluation of the criteria we will adjust the *Trialeurodes vaporariorum*/*Encarsia formosa* simulation model developed in our laboratory (van Roermund, this volume). A sensitivity analysis of this model showed that only two bionomic parameters of the parasitoid (longevity and development time) and a number of parameters related to the searching behaviour (such as walking speed, walking activity, width of search path, flight distance) have a significant impact on the reduction of the pest organism. Fecundity of the parasitoid was found to be a non-significant parameter at the low host-densities in glasshouse tomato crops. Assuming that the *B. argentifolii*-parasitoid systems resemble that of the *T. vap.*/*E. formosa*, we started characterizing the different parasitoid species with the significant parameters and the fecundity (for comparison with literature data). In this paper we present the development time, the longevity and the fecundity for different parasitoid species of *B. argentifolii*.

MATERIAL AND METHODS

Insects *B. argentifolii* was reared on poinsettia (*Euphorbia pulcherrima*, cv. Goldfinger), so were all parasitoids. The following parasitoid species were reared on *B. argentifolii* on poinsettia or obtained from a commercial company:

- *Encarsia formosa* Gahan (Aphelinidae) Beltsville strain, reared more than 4 years on *B. argentifolii*, uniparental

- *Eretmocerus mundus* Mercet. (Aphelinidae) obtained from *Bemisia* on melon, Spain, biparental
- *Er.* nr. *californicus* (Aphelinidae) obtained from Koppert B.V, biparental
- *Er.* sp. (Aphelinidae) obtained from Texas, uniparental
- *Amitus bennetti* Viggiani & Evans (Platygasteridae) obtained from California, uniparental

Although we anticipated to do all the experiments with all species at the same time, this proved to be impossible for technical reasons. Since we haven't finished experiments for all species, the species range may differ per experiment.
Space limitation prevents us from giving all details on experiments, these will be published elsewhere. All experiments however were carried out on poinsettia.

RESULTS AND DISCUSSION

Longevity The longevity without hosts differs between the tested species and is dependent on the temperature (Table 1). High longevity without hosts will be specifically important for parasitoids that are released in low density host populations. For the relation

Table 1.Longevity in relation to temperature.

	15 ^{0}C			20 ^{0}C			25 ^{0}C		
species	mean	SE	n	mean	SE	n	mean	SE	n
A. bennetti	29.2	1.6	22	26.2	1.8	25	18.9	0.9	32
		y=45.6 - 1.1 * T		r=0.98					
E. formosa (B)	46.9	3.9	19	35.5	2.7	20	30.0	2.6	21
		y=69.4 - 1.6 * T		r=0.97					
Er. californicus	38.7	2.9	26	34.0	1.6	27	18.7	1.4	24
		y=77.8 - 2.3 * T		r=0.96					
Er. sp. (Texas)	47.5	2.2	14	37.1	2.9	17	23.8	1.2	18
		y=83.6 - 2.4 * T		r=0.99					

Means followed by the same letters are not significantly different using the method of Games and Howell to compare means with unequal variances (Sokal and Rohlf, 1981).

to temperature, a linear regression was performed on data weighted by the inverse of their variance. From the regression formulas it becomes clear that the species are ordered in the table according to an increasing sensitivity to temperature, *A. bennetti* being the least sensitive and *Er.* sp. (Texas) being the most sensitive. Unplanned comparisons of regression coefficients using the T'-method (Sokal and Rohlf, 1981) showed that only the regression coefficients of *A. bennetti* and *Er.* sp. (Texas) differ significantly.

Development time The development time of the different species is given in Table 2. Mean development times are all below the development time for *B. argentifolii* on poinsettia (Enkegaard, 1993a), at 20 ^{0}C and 25 ^{0}C. However, Fransen (1994) reported a mean development time of *B. argentifolii* on poinsettia at the same temperatures lower than Enkegaard (1993), such that for 25 ^{0}C, the development of *B. argentifolii* is faster than that of *A. bennetti* and *Er.* sp. (Texas).

Linear regression was performed on the development rate and the threshold value at which

Table 2. Development time for the different parasitoid species.

	15 °C			20 °C			25 °C		
species	mean	SE	n	mean	SE	n	mean	SE	n
A. bennetti	72.2	1.2	13	41.7	0.3	102	27.6	0.4	28
E. formosa (B)	48.3	0.9	40	28.0	0.5	58	19.8	0.2	126
Er. sp. (Texas)	58.3	0.6	47	31.9	0.7	22	24.2	0.3	59

the development rate is zero (T_0) was estimated as the ratio of minus the constant over the regressioncoefficient. With T_0 the number of day degrees (DD) was calculated as DD = development time * ($T-T_0$). From Table 3 one can see that the value of DD is the lowest for *E. formosa* and the highest for *A. bennetti.*

Table 3. Parameters of linear regression on development rate vs. temperature.

species	a	b	r	est. T_0	DD
A. bennetti	-0.02	0.0024	0.96	10.0	400
E. formosa (B)	-0.03	0.0031	0.87	8.1	335
Er. sp. (Texas)	-0.02	0.0025	0.96	7.6	416

Fecundity The fecundity, parasitization rate and longevity with hosts has been assessed for *A. bennetti* and *Er.* sp. (Texas). Only females that laid eggs and completed the experiment (i.e. found dead in the clip cage) were used for analysis. Longevities in presence of hosts were about 10 times lower than longevities without hosts (Table 4).

Table 4. Fecundity, parasitization rate and longevity in presence of hosts.

species	parameter	mean	SE	n
Er. sp. (Texas)	fecundity	31.8	5.6	24
	parasitization rate	5.6	0.7	24
	longevity	5.8	0.7	24
A. bennetti	fecundity	26.0	3.2	31
	parasitization rate	10.6	1.2	31
	longevity	2.6	0.3	31

The fecundity of both species is in the range of 20 to 30. The fecundity and parasitization rate for *Er. sp* (Texas) is within the range of fecundities reported for *Er. mundus* (Tawfik et al., 1978) and *Er. californicus* (Powell and Bellows, 1992). The longevity with hosts is somewhat lower than reported for the above mentioned species. The longevity for *A. bennetti* is even lower, but the parasitization rate is much higher, resulting in a mean fecundity that is not significantly different from that of *Er.* sp. (Texas) (t=0.915). As a comparison, fecundities reported in the literature for *E. formosa* on greenhouse whitefly are often higher (van Roermund, 1992) with an extreme of 149.9 (Vet and van Lenteren, 1981). Enkegaard (1993) found a mean fecundity of *E. formosa* parasitizing *B. argentifolii* on poinsettia (cv. Angelica) of resp. 85 and 96 at 22 and 28 ^{0}C, which is also much higher than found for the two species that we studied. This was due to much higher longevities, since the parasitization rates found by Enkegaard (1993) were 5.6 at 20 ^{0}C and 10.4 at 25 ^{0}C.

Based on the parameters we studied *A. bennetti* appears to be the least efficient parasitoid species having the longest development time, the shortest longevity and the lowest fecundity. However, this species has a high parasitization rate (in the range of commercial *E. formosa*) compared to *Er.* sp. (Texas) and thus might be an efficient natural enemy in inundative releases. Studies with the simulation model showed that fecundity did not significantly affect the reduction in whitefly numbers (van Roermund, this volume). Particularly at low host densities, a good searching efficiency might be much more important than high fecundity. From preliminary studies on the walking speed of two parasitoid species we know that the walking speed of *Er. californicus* is faster and straighter than of *E. formosa*, indicating that it might be a better searcher than *E. formosa*. Since the *Eretmocerus* spp. we tested have similar development times as *E. formosa* but a lower longevity with hosts present, it will be interesting to see which species turns out to be the most efficient. The data presented in this paper will be entered in the simulation model together with the behavioural parameters to evaluate which combination of parameters is best for a high reduction of host population numbers and which parameters are most suitable as estimators of the efficiency of parasitoid species. Subsequently, predictions from the model will be verified with greenhouse releases of the parasitoid species that are expected to be the most efficient in reducing numbers of whiteflies.

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LIFE TABLES OF *HYPOASPIS MILES* PREYING ON MUSHROOM SCIARID LARVAE, *LYCORIELLA SOLANI*, AND MOULD MITES, *TYROPHAGUS PUTRESCENTIAE*

A. ENKEGAARD, M. A. SARDAR[1] & H. F. BRØDSGAARD
Department of Plant Pathology and Pest Management, Danish Institute of Plant and Soil Science, Lottenborgvej 2, DK-2800 Lyngby, Denmark
[1] Dept. of Entomology, Bangladesh Agricultural University, Mymensingh, Bangladesh

1. Introduction

The soil-inhabiting, polyphagous predatory mites *Hypoaspis miles* and *H. aculeifer* (Acari: Hypoaspidae) have recently been marketed as biological control agents against sciarids that constitute a serious pest problem in many glasshouse crops and in the mushroom industry. The mites are part of the European fauna and occur naturally in glasshouses. Their prey consists of soil-inhabiting stages of many different organisms including larvae of sciarids and shore flies, collembola, nematodes and pupae of thrips, leafminers and gallmidges (e.g. Gillespie & Quiring, 1990, Enkegaard *et al.*, 1995). Research on *H. miles* and *H. aculeifer* have shown their potential to control infestations of sciarid flies and thrips in cultures of Cyclamen, Poinsettia, Saintpaulia, Pelargonia, cucumber and mushrooms (Gillespie & Quiring, 1990; Glockemann, 1992; Chambers & Lind, 1993; Chambers *et al.*, 1993). Apart from biocontrol experiments, research on the biology of *Hypoaspis*-mites is still limited and originates mainly from investigations of *H. aculeifer*. For *H. miles*, only relatively few studies have been made (e.g. Glockemann, 1992; Shereef *et al.*, 1980; Wright & Chambers, 1994). An increased knowledge on the biology of *H. miles* will enhance the possibilities for its optimal use in biological control. Therefore, the present study on the influence of the prey species on the life table parameters of *H. miles* was undertaken.

2. Materials and Methods

Cultures of *H. miles* fed on mushroom sciarid larvae (*Lycoriella solani* (Diptera: Lycoriidae)) and mould mites (*Tyrophagus putrescentiae* (Acari: Acaridae)), respectively, were established in a climate room at 22°C, 65% r.h., 16:8 l:d. Two generations elapsed in these cultures before the experiments were initiated in climate cabinets at 20°C and 16:8 l:d. Cohorts of *H. miles* were initiated with max. 24 hour old eggs obtained from the respective cultures and placed in small containers with moistened plaster of Paris-charcoal layers. The humidity inside the containers were about 75%. Five replicates, each containing 10-14 eggs, were used per prey. The cohorts were observed at regular intervals until death of the emerged adults. Eggs produced during the adult phase were removed and kept isolated for subsequent sexing of emerging adults. Sciarid larvae or mould mites were added to the containers at the time of observation. Prey was supplied in abundant numbers except for a period of 24 days where shortage in the supply of sciarid larvae occurred. This period of shortage arose after emergence of adults in the cohorts. However, the mites never experienced a complete lack of food and no mites died during this phase of the experiment.

3. Results

The influence of the prey species on developmental time, juvenile mortality, reproductive periods, adult longevity, sex-ratio among off-springs and demographic parameters is shown in tabel 1.

The egg production of *H. miles* fed on sciarid larvae decreased for a 10-day period 14 days after the onset of the food shortage period, but was resumed at the same rate immediately after restoration of an ample food supply (data not shown). To estimate the expected level of egg production if food had been ample enough, the period with reduced egg production was removed from the observations and replaced with the observations obtained after the food supply had retained the normal level. The resulting average cumulative egg production per female as a function of female age was described by the following model

$$F_x = \alpha - \beta e^{-\delta x} \qquad (1)$$

where F_x is the daily cumulative egg production (eggs/♀), x is the age of females taken from the onset of egg-laying and α, β, δ are constants. The model was fitted by nonlinear least square technique to the adjusted egg production data for *H. miles* fed on sciarid larvae, as well as to the data for egg production of *H. miles* fed on mould mites (Table 1, Fig. 1). The estimated parameters for the two food types were significantly different, as also evidenced by the obvious difference between the two curves in Fig. 1. Thus, when *H. miles* were fed on mould mites, the increase in egg production diminished to virtually zero already after 28 days. In contrast, when the predatory mites were fed on sciarid larvae, *H. miles* was able to keep the egg production increasing notably throughout the oviposition period. From model (1), the egg production (±S.E.) of *H. miles* to be attained through a 53 days oviposition period with an ample supply of sciarid larvae was estimated to be 44.4±4.33 eggs/♀. In comparison, the average number of eggs/♀ (±S.E.) fed on mould mites was 22.43±1.79 through an oviposition period of 68.5 days. The daily egglaying decreased through the oviposition period from 1.2 to 0.6 and from 1.6 to 0.01 per female *H. miles* fed on sciarid larvae and mould mites, respectively.

4. Discussion

The prey species offered to *H. miles* significantly influenced many of the biological parameters of the predator. Thus, when preying on mushroom sciarid larvae, as compared to mould mites, *H. miles* had a shorter developmental time, a lower juvenile mortality, a shorter oviposition period and female longevity, a larger egg production and a higher proportion of females among the off-springs, resulting in higher rates of net reproductive capacity and innate capacity for increase. Shereef *et al.* (1980) have likewise reported that various biological characteristics of *H. miles* may be significantly influenced by the prey species offered.

The present egg production of *H. miles* fed on mould mites is in general agreement with the observations on *H. miles* made by Shereef *et al.* (1980) using the same prey species and by Wright & Chambers (1994) using grain mites (*Acarus siro*) as food. Shereef *et al.* (1980), in an experiment conducted by at 25°C, found the same postoviposition period, but shorter preoviposition and oviposition periods of *H. miles* fed on mould mites than found presently which, presumably, is due to the differences in experimental temperature. Wright & Chambers (1994) observed a developmental time for *H. miles* fed on grain mites of 17.5 days which is longer than the developmental time found in the present study for *H. miles* fed on mould mites, indicating differences in the nutritional value between grain mites and mould mites. From the productivity study of *H. miles* fed on grain mites conducted by Wright and Chambers (1994) at 21°C an estimate of r_m of 0.065 day^{-1} can be obtained. This rate of innate capacity for increase of *H. miles* is in between the r_m-values of 0.054 day^{-1} and 0.075 day^{-1} found presently for predators fed on mould mites and sciarid larvae, respectively.

Comparison of the present results on the biology of *H. miles* with results for *H. aculeifer* fed on mould mites at comparable temperatures, indicate that the latter predator has a longer developmental time, a higher juvenile mortality, a higher egg production, a comparable sex-ratio among off-springs and higher rates of net reproductive capacity and innate capacity for increase (Lobbes and Schotten, 1980; Barker, 1969; Murphy & Sardar, 1991).

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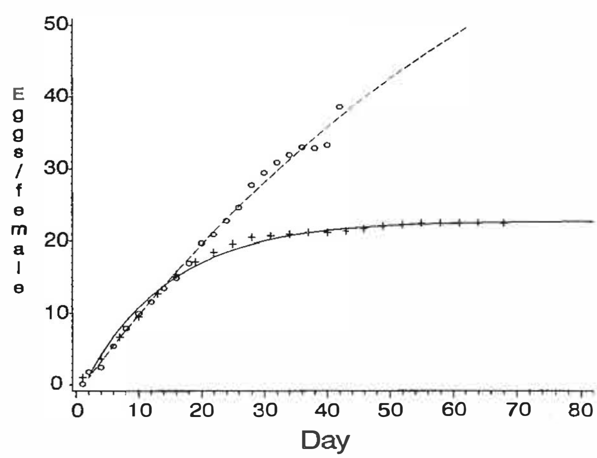

Fig.1. Age-specific cumulative eggs/♀ during the oviposition period as estimated from model (1) for *H. miles* fed on sciarid larvae (circles, dotted line) and as observed when *H. miles* fed on mould mites (crosses, solid line).

Table 1. Stage-specific juvenile developmental time and mortality, average reproductive periods, adult longevity, sex-ratio (♀/(♀+♂)) and demographic parameters, as well as parameter estimates (±S.E.) and R^2-values for model (1) describing the age-specific cumulative egg production for *Hypoaspis miles* fed on sciarid larvae and mould mites, respectively. The values are means±S.E. Figures in parentheses are number of replicates. Values are significantly different between prey species at the 1% level, if followed by different letters. [1234] indicate analysis used: [1]: accelerated failure time model; [2]: χ^2-analysis; [3]: Median 2-sample test; [4]: Fischer-Behrens test.

	Mushroom sciarid larvae	Mould mites
Developmental time[1] (days)		
Egg	2.9±0.10a (58)	3.6±0.12b (50)
Larvae	1.2±0.05a (58)	1.4±0.07b (50)
Protonymphs	5.9±0.12a (57)	7.5±0.16b (50)
Deutonymphs	4.6±0.09a (57)	4.5±0.25a (42)
Total	14.5±0.16a (57)	16.6±0.27b (42)
Mortality[2] (%)		
Egg	0.00±0a (58)	0.00±0a (50)
Larva	1.72±1.7a (58)	0.00±0a (50)
Protonymphs	0.00±0a (57)	16.00±5.2b (50)
Deutonymphs	1.75±1.7a (57)	4.76±3.3a (42)
Total immature	3.45±2.4a (58)	20.00±5.7b (50)
Preoviposition period[3] (days)	5.1±0.49a (5)	8.9±5.05a (5)
Oviposition period[3] (days)	53.2±1.59a (35)	68.5±2.15b (33)
Postoviposition period[3] (days)	32.1±4.16a (27)	37.1±5.12a (23)
Female longevity[1] (days)	82.0±4.55a (35)	109.6±5.92b (33)
Male longevity[1] (days)	168.2±39.8a (11)	219.4±41.4a (7)
Egg production, model (1)		
Parameters[4]		
α	94.632±20.515a (22)	22.754±0.198b (23)
β	95.936±20.088a (22)	24.871±0.588b (23)
δ	0.0122±0.0033a (22)	0.0731±0.0034b (23)
R^2-value	0.994	0.989
Sex-ratio[2] (♀/(♀+♂))	0.66±0.015a (1010)	0.54±0.03b (273)
Demographic parameters		
R_0	27.352	9.097
r_m (days^{-1})	0.0747	0.0543
λ	1.0776	1.0558
Generation time (days)	44.28	40.67
Doubling time (days)	9.3	12.8

EFFECT OF SELECTED CULTIVARS ON *ORIUS INSIDIOSUS*

G. M. Ferguson[1] & J. S. Schmidt[2]
[1]Ontario Ministry of Agriculture, Food, & Rural Affairs, Harrow Research Station, Harrow, Ontario N0R 1G0
[2]Dept. of Environmental Biology, University of Guelph, Guelph, Ontario N1G 2WI

Abstract

The effects of selected cultivars of greenhouse vegetables on several life history parameters of *O. insidiosus* were studied to determine their suitability as plant hosts. Two cultivars each of tomato, cucumber, and sweet pepper were evaluated. *Orius insidiosus* was able to oviposit on all the cultivars tested. The mean egg-laying rate was higher on petioles from cucumber than on those from pepper. The percentage hatch was high on all the cultivars but hatching was higher from petioles of cucumber than from those of pepper. Survival of first instars was high on all the cultivars. The predators were able to consume thrips in dishes containing leaf disks from all the cultivars tested. However, the mean consumption of thrips by adult female *O. insidiosus* was reduced in dishes containing leaf disks of cucumber indicating that the leaf surface properties of cucumber may interfere with the consumption of thrips by female *O. insidiosus*. There was no evidence that the leaf surface properties of tomato and pepper interfere with the consumption of thrips.

Introduction

Orius insidiosus (Say) (Heteroptera: Anthocoridae) is an effective natural enemy of the western flower thrips, (*Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae)), a major pest of greenhouse vegetable crops in Ontario (Shipp et al. 1991). The majority of greenhouse vegetables belong to the families Solanaceae and Cucurbitaceae. Some species of these plant families can adversely affect the development, survival, oviposition, and predatory activity of a variety of arthropod species (Omoy 1987, Bonjour & Fargo 1989, Nihoul 1993). Greenhouse vegetable crops can have similarly adverse effects on *O. insidiosus*. In a study by Riudavets et al. (1993), two *Orius* species (*O. laevigatus* (Feiber) and *O. majusculus* (Reuter)) reproduced on carnation, pepper, strawberry, bean, and cucumber plants, but not on tomatoes. The failure of both *Orius* spp. to control *F. occidentalis* on tomatoes was attributed to their inability to reproduce on this crop (Riudavets et al. 1993).

This study evaluated the effects of selected cultivars of greenhouse tomato, cucumber, and sweet pepper on oviposition, prey consumption, and survival of immature *O. insidiosus*. These parameters were chosen because of their importance in the establishment of *O. insidiosus* in greenhouse crops and their role in the control of thrips.

Materials and methods

Two cultivars each of tomato (Trust™ and KR381™ from De Ruiter Seed Co. Ltd.), cucumber (Jessica™ from Rijk Zwaan Seed Co. Ltd. and Corona™ from De Ruiter Seed Co. Ltd.) and sweet pepper (Cubico™ from De Ruiter Seed Co. Ltd. and Mazurka™ from Rijk Zwaan Seed Co. Ltd.) were used.

(a) Effect of selected cultivars on the egg-laying rate of *O. insidiosus* and hatching

Petioles were taken from leaves arising between the third and fifth nodes below a growing point. Egg-laying on the various cultivars was evaluated by placing individual females (6-10 days old) in petri dishes which held a disk of Whatman ™ filter paper, a 2-cm petiole section, and an egg card of *E. kuehniella*. Each female was used only once and remained with the substrate for 24 hours in a growth-room at 24 ± 0.5°C, 70 ± 10% RH and 16L:8D. Examination of eggs for hatching began five days after oviposition and continued daily for four days to ensure that all hatching was observed. Each treatment was replicated ten times on seven separate dates.

(b) Effect of selected cultivars on the survival of first instars.

Leaf disks with a diameter of 3.5 cm served as the test substrate. Tomato leaf disks were cut from leaves collected from the middle and lower strata of the plant canopy, whereas cucumber and pepper leaf disks were cut from leaves collected from the upper canopy. The upper surface of each leaf disk faced the bottom of the petri dish. Nymphs were placed individually on the leaf disks and lids which had a screened opening (2-cm diameter), covered the dishes. Four eggs of *E. kuehniella* were provided as food. The eggs were placed equidistantly around the perimeter of the leaf disk. Because the leaf disks were not fastened to the bottom of the dish, both upper and lower surfaces were accessible to the nymphs.

Two days after the nymphs were placed on the leaf disks, the dishes were examined daily for the presence of second instars. The second instars were recognized by their size and the presence of exuviae in the dishes. Successful development to the second instar and the time taken for development to this stage were recorded. The number of *E. kuehniella* eggs consumed was also recorded. Each treatment was replicated 16 times on three separate dates.

(c) Effect of selected cultivars on the consumption of *F. occidentalis* by adult females

The test arenas consisted of petri dishes with 4-cm diameter leaf disks that were placed inside 4.5-cm diameter petri dishes. The effects of leaf disks from six cultivars were evaluated. An adult, female *O. insidiosus* was placed with 10 adult, female *F. occidentalis* in each arena. Dishes were kept in a growth chamber at 70 ± 10% RH, 24 ± 0.5°C and a photoperiod of 16L:8D for six hours. To determine whether the leaf disks contributed to mortality, the mortality of thrips was assessed on leaf disks in the absence of female *O. insidiosus*. The mortality of thrips was also assessed in dishes that did not contain leaf disks, with and without female *O. insidiosus*. Each treatment was replicated three times on eleven separate dates.

Results and Discussion

Egg-laying rate and percent hatch (Table 1), and survival of first instars were largely unaffected by plant species and cultivar.

TABLE 1. Effect of selected cultivars on the number of eggs laid by *Orius insidiosus* within 24 hours, and percent hatch.

Crop	Cultivar	Total No. Of Females[1] Observed	Total No. Of Eggs Laid	Mean No. Of Eggs Laid/Female Per Day (95% CI)[2]	Percent Egg Hatch (± SD)[3]
Cucumber	Corona	69	281	3.2 ab (2.2, 4.2)	84 ± 25 a
	Jessica	67	297	3.4 a (2.5, 4.5)	85 ± 28 a
Tomato	KR381	69	194	2.1 b (1.3, 3.0)	81 ± 28 a
	Trust	68	177	2.0 b (1.2, 2.9)	79 ± 29 a
Pepper	Cubico	66	239	2.7 ab (1.9, 3.7)	72 ± 30 a
	Mazurka	67	174	1.9 b (1.3, 2.8)	71 ± 34 a

[1]Females were 8-12 days old.
[2]Before carrying out an ANOVA, a $\sqrt{x+0.5}$ transformation was applied to the number of eggs laid. Original units of means and their asymmetrical confidence limits are reported.
[3]Values within a column followed by the same letter are not significantly different ($P > 0.05$); least significant difference test (SAS Institute 1990).

Survival of first instars on all the cultivars was not significantly different, and was 83-100%. However, consumption of thrips was affected by plant species and was reduced in the presence of leaf disks of cucumber (Table 2).

TABLE 2. Effect of the leaf surfaces of selected cultivars on the consumption of adult, female *Frankliniella occidentalis*[1] by adult, female *Orius insidiosus*[2]

Plant Species	Cultivar	Total no. of females observed	No. of *F. occidentalis* killed/6 hr/female *O. insidiosus* (± SD)[3]
Cucumber	Corona	33	1.8 ± 0.5 b
	Jessica	33	1.9 ± 0.6 ab
Tomato	KR381	33	2.3 ± 0.6 ab
	Trust	33	2.0 ± 0.7 ab
Pepper	Cubico	33	2.5 ± 1.0 a
	Mazurka	33	2.5 ± 1.1 a
No leaf disks		33	2.5 ± 0.9 a

[1]Ten prey and one female *O. insidiosus* per dish.
[2]*Orius insidiosus* were 6-10 days old.
[3]Values within a column followed by the same letter are not significantly different ($P > 0.05$); least significant difference tests (SAS Institute 1990).

These experiments did not reveal any factors that would prevent the establishment of *O. insidiosus* in any of the cultivars tested. Petioles from all the cultivars were acceptable as oviposition sites and hatch was high (71-85%) in all the cultivars. The results of this study also indicate that whereas the leaf surfaces of tomato and pepper did not interfere with consumption of thrips, the leaf surfaces of the cucumber cultivars did interfere with consumption. The hairy leaf surfaces of cucumbers could have impeded locomotion, thereby interfering with capture of thrips. In studies with another beneficial arthropod, Peterson (1990) observed that the leaf surfaces of cucumber impeded the locomotion of *Amblyseius cucumeris* (Oudemans) (Acari: Phytoseiidae). The greater egg-laying rate and hatch by *O. insidiosus* observed on the cucumber cultivars could compensate for the lower consumption of thrips observed in dishes with leaf disks of this plant species. Overall, the results indicate that all the cultivars tested will be good candidates for the biological control of thrips using *O. insidiosus*.

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RECENT TRENDS IN INTEGRATED AND BIOLOGICAL PEST AND DISEASE CONTROL IN THE NETHERLANDS

Joanne J. Fransen
Research Station for Floriculture and Glasshouse Vegetables, Aalsmeer, The Netherlands

Summary
A concise overview is given on the research of integrated pest and disease control in floricultural crops in the Netherlands referring to supervised, biological and chemical control and host plant resistance.

Introduction
Due to the flat countryside, temperate climate, favourable infrastructure and densely populated areas, the glasshouse industry in the Netherlands has expanded to an area 10320 ha, of which 4727 ha consists of vegetable crops and the rest is divided in 4230 ha cut flowers, 1078 ha pot plants and 285 ha bedding plants. The floricultural industry is characterized by its diversity in products being grown in highly specialized facilities demanding specific knowledge about the crop physiology, nutrition, climate control and crop protection. Launching of the 'Multi Year Crop Protection Program' by the Dutch government in 1990 has had an important impact on the development of incentives to reduce the overall use of pesticides in agriculture and horticulture by at least 50% in the year 2000. Three different strategies have been defined, aimed at the reduction of the dependence on chemical pesticides, the reduction of the use of chemical pesticides and the reduction of the emissions of chemical pesticides to the environment, particularly ground and surface water and air (Anonymous, 1991).

The objective of integrated pest and disease management is to allow economic and competitive farming with as few as possible adverse effects of crop protection measures on the environment, the user and the consumer. To achieve these objectives all organizations involved in horticulture related to the production chain of floricultural products ranging from the plant breeders, propagators, growers and auctions to the extension services, policy makers and research organizations are taking part. Different research activities to obtain a reduction of pesticide use are being carried out and some of these are summarized below.

Supervised control
The term supervised control relates to the use of control measures at the most optimal time. A decision to treat a crop may be based on subjective criteria and timing is often suboptimal. By registration of what chemicals and which quantities are used and when they were applied, the grower gets a better overview of his crop protection management. For instance, trials in chrysanthemum have been carried out for establishment of action threshold levels by monitoring the crop and using sticky traps. It takes about 2 to 4 hrs weekly to inspect an area of 1 to 3 ha. Except for information on the pests and diseases inspection of the crop also provides information on local effects such as dry or wet spots and results of pesticide applications. Guldemond (1993) found that the density of the aphid *Myzus persicae* and *Aphis gossypii* can be estimated by incidence (presence/absence) counts. Yellow sticky traps are good indicators for presence of leafminers. Considering

western flower thrips, the relation of thrips on blue as well as yellow sticky traps and presence in the crop, varies depending on the season. When monitoring western flower thrips in roses a relationship between catches on blue sticky traps and numbers of damaged flowers was observed. Another example of supervised control is being developed by the chemical company Merck, Sharp and Dohme in the Netherlands. In roses spider mites, *Tetranychus urticae*, can be a pest and the chemical abamectin (vertimec®) is one of the chemicals for control. The company's aim is to optimize the use of this chemical to reduce the risk of inducing acaricide resistance.

Research on the epidemiology of *Botrytis cinerea* in gerbera and rose showed that spore counts on traps did not show a seasonal pattern. The number of lesions caused by conidial infection of gerbera flowers following incubation, however, showed a distinct seasonal pattern, being positively correlated with relative humidity and negatively correlated with global radiation outdoors (Kerssies, 1994). Thus, a warning system is being developed for *B. cinerea* in gerbera and roses based on linear regression analysis in which the number of lesions on the flowers in the post-harvest stage is the dependent variable and relative humidity inside the glasshouse and radiation outside the glasshouse are the independent variables. On roses 5 lesions per flower are enough to declassify a flower, and on gerbera 50 to 100 lesions result in declassification. Another disease being subject in a supervised-control programme is powdery mildew, *Sphaerotheca pannosa*, in roses. Monitoring was carried out in different glasshouses by weekly counting the numbers of small composed leaves with powdery mildew. Epidemics occurred independent of weather conditions and seasonal influences, nor was the origin of an epidemic correlated with a certain location in the glasshouse. The action threshold level was established being 5.28 infected small leaves per m2 for roses showing partial resistance to powdery mildew. Generally, after passing this level of infestation three applications of chemical fungicides were carried out with four-day intervals to control the disease. Monitoring techniques and action threshold levels are presently being tested in commercial glasshouses.

Many growers already use sticky traps to keep track of the presence/absence and fluctuations of numbers of flying insects, but monitoring in the crop and keeping a detailed record of infestations and treatments will have to become common practice in the future.

Biological Control

Biological control of pests in ornamentals has only started recently and was carried out on a more or less experimental scale on about 50 ha in 1992 which amounts to 1% of the total production area of ornamentals (Fransen, 1993). Results have been promising and the number of growers applying natural enemies is growing fast. Integrated control involving biological control of at least two insect/mite pests is estimated to have increased up to 250 ha of ornamentals in 1995. Usually damage threshold levels are low because whole plants, flowers and leaves, are sold and should be of good quality and impeccable appearance. Thus, often "overkill" numbers of natural enemies are used in inundative releases. However, introducing high numbers of natural enemies may be very costly and not achieve optimal results. Parasitoids in high densities may show mutual interference and predators may show cannibalistic behaviour. Thus, alternative food sources such as pollen or other prey, may contribute to a more cost-effective use of natural enemies.

Applications of microorganisms against individual pests like the baculovirus against beet army worm (Spodex®), *Bacillus thuringiensis* against other noctuids, insect parasitic nematodes against sciarids and vine weevil, and the fungus *Verticillium lecanii* (Mycotal®) against whitefly has been more readily used than in the past, because their easy integration with chemical control. Recently, a nematode species has been found showing perspectives for control of snails and slugs (Glen et al., 1994). Several insect pathogenic fungi, such as *Aschersonia aleyrodis*, *V. lecanii* and *Paecilomyces fumosoroseus*, are being tested for control of greenhouse whitefly, *Trialeurodes vaporariorum*, and silverleaf whitefly, *Bemisia argentifolii* (Fransen, 1994). Some of these fungi also infect aphids and thrips. As mass production of these microorganisms becomes more advanced, interest in their use against pests and diseases is growing. Beneficial microorganisms are tested for control of plantpathogenic fungi in rhizosphere and phyllosphere. The non-pathogenic *Fusarium oxysporum* isolate no. 618-12 can induce resistance in carnation against the pathogenic *Fusarium oxysporum* f.sp. dianthi (Postma & Rattink, 1992). Also several antagonistic fungi, such as *Streptomyces* spp. and *Trichoderma* spp. are presently being tested against *Phytophthora* spp. and *Pythium* spp. A number of fungi are being tested against powdery mildews, like *V. lecanii* (Verhaar et al., 1993). Several bacteria and yeasts show antagonistic characteristics, suppressing post-harvest infection of *Botrytis cinerea* (Kerssies, 1993).

Host-plant resistance

Ornamentals are characterized by the large number of different cultivars showing differences in growth, colour, shape and keepability. At the moment also flower fragrance has become an important breeding characteristic. Resistance to pests and diseases always had a lower priority compared with trends and demands from salesmen, retailers and consumers. Nevertheless, many cultivars show resistance against pests and diseases and testing for these characteristics should be included in official breeding programmes. Chrysanthemum cultivars show differences in resistance to western flower thrips and leafminer pests (e.g. van Dijk et al., 1993; van Dijken et al., 1994). Rose cultivars show differences in susceptibility to powdery mildew and *B. cinerea* infection and saintpaulia in susceptibility to *B. cinerea*. Several chrysanthemum cultivars show resistance against infection by white rust, *Puccinia horiana*. Host-plant resistance may result in lower infection rates by plant pathogens or lower survival and developmental rates in insect populations. Thus, less chemical treatments are necessary, and biological control may be successfully used whereas in susceptible cultivars it is not (Fransen & Tolsma, 1992). Natural enemies may also directly be influenced by host-plant characteristics like attraction of predators by the production of cues as a reaction on spider mite infestation (Dicke et al., 1990) or hairiness or waxiness impairing mobility of natural enemies.

Chemical control

The aim in integrated pest and disease management is the use of different control strategies which are preferably non-chemical. However, chemical control will be used whenever alternatives are absent. Intensive use of chemicals can lead to resistance in the target organism, like in silverleaf whitefly against the selective compound buprofezin (Applaud®) (Cahill et al., 1994). Resistance against fungicides has also been reported, like white rust in chrysanthemum showing resistance against ergosterol biosynthesis inhibitors. Alternation of chemicals belonging to different working spectra is necessary to decrease the risk of resistance.

Discussion

A wide range of organisations participate in aiming to achieve a decrease of the dependence upon chemical pesticides and a reduction of use and emission. However, if new crop protection and production programmes do not offer clear economic advantages to the growers, implementation is hard to achieve. Growers perceive integrated pest and disease management as knowledge-intensive, time consuming and more risky. The zero-tolerance for end products which is presently being valid for exports to certain countries (around 10 to 17% of total export) has become the standard for almost all products, considered from the grower's point of view. When they offer their products to the auction, they do not know beforehand to which country their product is going to be exported. Differentiation of the market system with contracting of certain growers to produce for the "zero-tolerance" market can save unnecessary use of chemicals. Regular support and information from advisory services is needed even to motivate the grower with regard to common methods for reduction of chemicals like good sanitation and the maintenance of spraying equipment. Still more effort has to be dedicated to extension and education of the grower. And most of all, economic incentives need to be created for growers to move from conventional to integrated farming systems.

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SURVEY OF AUSTRALIAN NATIVE NATURAL ENEMIES FOR CONTROL OF THRIPS.

S. Goodwin and M. Y. Steiner
Horticultural Research and Advisory Station, NSW Agriculture, Box 581, Gosford 2250, NSW, Australia

Abstract
Western flower thrips, *Frankliniella occidentalis* (Pergande), was detected in Australia for the first time in April 1993 (Malipatil *et al.* 1993). Representative areas of Australia were surveyed for natural enemies of thrips, particularly for those beneficials with potential for commercial development. The project commenced in April 1994 and is ongoing. A table of predators and parasitoids collected in association with thrips during these surveys is presented.

Introduction
Western flower thrips, *Frankliniella occidentalis* (Pergande), was first detected in Australia in April 1993 in Western Australia. Subsequently it has been found in NSW, Tasmania, Queensland and South Australia. Initial attempts to limit its spread failed and it is now recorded on over 60 properties country-wide. A national program was put in place to deal with it and funding for a biological control option was provided by the New South Wales Horticultural Stock and Nurseries Act and the Horticultural Research and Development Corporation .

Methods
Collections of thrips and associated beneficials were made in New South Wales, Western Australia, Queensland, Victoria, and South Australia in a variety of habitats. Sampling methods included sweep net-sampling, beating, washing, and aspirating individuals, depending upon the host. The majority of samples were preserved as a reference source for future collections; however, where possible, live beneficials were also collected and reared in the laboratory for assessment as effective controlling agents for thrips. Methods employed for collecting, processing, and small-scale rearing of both thrips and beneficials are described in Steiner *et al.* (1996) and Steiner and Goodwin (1996).

Results
Over 650 collection sites were visited in the period 8 April 1994-15 May 1995. Predators and parasitoids collected in association with the 117 species of thrips identified are summarized in Table 1 and detailed information given in Steiner and Goodwin (1996). There were six species of parasitoids, 12 species of hemipteran bugs, 10 species of predatory thrips, 48 species of predatory mites (mostly phytoseiids), and two pathogens, *Neozygites* sp. and *Entomophthora* sp.

The most frequently collected parasitoid was the eulophid wasp *Ceranisus menes* (Walker) (121 sites). One dark-bodied strain is presently in culture, being reared on *Frankliniella schultzei* (Trybom). Other parasitoids were rarely taken except *Thripobius semiluteus* Bouchek in association with *Heliothrips haemorrhoidalis* Bouchée.

The anthocorid bug *Orius tantillus* (Motschulsky) was common in NSW and QLD but was difficult to rear in the laboratory and did not have a major impact on thrips in confined areas. *Orius armatus* Gross is less common but has been reported as having an impact on field populations of thrips in carnations in Western Australia (Cook 1995). A mirid bug, the apple dimpling bug, *Campylomma liebknechti* (Girault), shows promise but may prove a pest in some crops.

Over 36 species of phytoseiids were identified, of which *Amblyseius lailae* Schicha, *A. largoensis* gp. sp., *A. lentiginosus* Denmark & Schicha, *A. masiaka* Blommers & Chazeau, *A.*

montdorensis Schicha, *A. sullivani* Schicha & Elshafie, *A. peltatus* Merwe, and *A. waltersi* Schicha are in long-term culture, along with the laelapids *Stratiolaelaps miles*, and two *Hypoaspis* spp.

Several of these species perform better against thrips (*F. schultzei*) than *Neoseiulus cucumeris* (Oudemans), *Isipheius degenerans* (Berlese) and *Stratiolaelaps miles* in small rearing units. Further research is planned to assess the biology and efficacy of the predators and parasitoids in culture. Other areas will be surveyed, particularly the Northern Territories.

Table 1. Predators and parasitoids collected in association with thrips in Australia 1994/95.

ORDER: FAMILY	IDENTIFICATION	FREQ	STATE
Hym.: Eulophidae	*Ceranisus menes*	121	NSW, WA, QLD, NT, SA
	Goetheana shakespearei	4	WA, NT
	Entedonastichus ? dei	1	NSW, NT
	Thripobius semiluteus	17	NSW
Hym.: Trichogrammatidae	*Megaphragma* sp.	8	NSW, QLD, SA
Hym.: Mymaridae	*Camptoptera* sp.	4	NSW, QLD, WA
Hem.: Anthocoridae	*Orius armatus*	5	NSW, QLD, WA
	O. heterorioides	1	QLD
	O. tantillus	66	NSW, QLD, WA
	Cardiastethus minutus	1	QLD
	Lasidiella spp.	1	NSW, QLD
	Lyctocoris campestris	2	QLD, WA
	Xylocoris sp.	1	SA
	X. afer	1	WA
	X. queenslandicus	1	QLD
Hem.: Lygaeidae	*Germalus* sp.	1	NSW
Hem.: Miridae	*Camptoptera liebknechti*	41	NSW, QLD, SA, WA
Hem.: Nabidae	*Nabis kinbergii*	6	NSW, QLD
Thys.: Aeolothripidae	*Andrewarthaia kellyana*	8	NSW, QLD, WA
	Desmothrips n. sp.	8	WA
	Desmothrips australis	32	NSW, WA
	D. bagnalli	5	NSW, QLD
	D. obsoletus	2	NSW, QLD, SA
	D. propinquus	37	NSW, QLD, WA, SA, VIC
	D. reedi	8	NSW, QLD, WA

	D. steeleae	4	WA
	D. tenuicornis	29	NSW, QLD, WA
	Mymarothrips garuda	1	NT
Thys.: Phlaeothripidae	*Haplothrips bituberculatus*	5	NSW
	Haplothrips victoriensis	5	NSW, WA
	Karnyothrips flavipes	1	QLD
	Karnyothrips sp.	1	NSW
Acari: Adamystidae	*Adamystis* sp.	1	NSW
Acari: Anystidae	*Walzia*? sp.	15	NSW, QLD
	Walzia australica	1	QLD
Acari: Ascidae	*Asca* spp.	4	WA
	Cheiroseius sp.	1	NSW
	Lasioseius sp.	1	NSW
	Lasioseius subterraneus	1	NSW
	Proctolaelaps sp.	5	NSW, QLD
Acari: Laelapidae	*Hypoaspis* s. l.	3	NSW, QLD
	Pseudoparasitus spp.	2	NSW, WA
	Stratiolaelaps miles	3	NSW, QLD
Acari: Ologamasidae	*Heydeniella* sp.	1	NSW
Acari: Phytoseiidae	*Amblyseius bellinus* gp. sp.	2	NSW, WA
	A. carverae	1	SA
	A. dieteri	4	NSW, WA
	A. dodonaeae	1	NSW
	A. harveyi	1	WA
	A. lailae	5	NSW
	A. largoensis gp. sp.	50	NSW, QLD, SA, VIC, WA
	A. lentiginosus	16	NSW, QLD, SA
	A. lentiginosus gp. sp.	1	QLD
	A. ?markwelli	1	NSW
	A. masiaka	12	NSW, QLD, SA
	A. messor	3	WA
	A. montdorensis	13	NSW, QLD, SA, NT

	A. n. sp. nr *montdorensis*	2	WA
	A. sp. nr *noosae*	1	NSW
	A. peltatus	1	NSW
	A. queenslandicus	2	QLD
	A. sturti	2	NSW
	A. sullivani	1	QLD
	A. nr *sullivani*	4	NSW, QLD
	A. tareensis gp. sp.	2	NSW, QLD
	A. waltersi	4	QLD, SA, WA
	A. womersleyi	1	NSW
	Euseius elinae	19	NSW, QLD, SA, WA
	Euseius neovictoriensis	18	NSW, QLD, SA
	E. victoriensis	15	NSW, SA, QLD, WA, VIC
	Neoseiulella dossei	2	WA
	N. doreenae	1	SA
	N. steveni	3	SA, WA
	Paraphytoseius n. sp.	1	QLD
	Phytoseius fotheringhamiae	2	NSW
	P. leaki	1	NSW
	P. rubiginosae	1	SA
	P. woolwichensis	1	QLD
	Typhlodromus brisbanensis	2	NSW, QLD
	T. novaezealandiae	2	NSW

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NATURAL ENEMIES OF WESTERN FLOWER THRIPS INDIGENOUS TO CALIFORNIA ORNAMENTALS

Kevin M. Heinz[a], Lily M. Heinz[b], & Michael P. Parrella[c]
[a]Biological Control Laboratory, Department of Entomology, Texas A&M University, College Station, TX 77843-2475, [b]Department of Biology, California State University, Sacramento, CA 95814, [c]Department of Entomology, University of California, Davis, CA 95616, U.S.A.

Abstract
Field- and greenhouse-grown carnations, chrysanthemums, and roses were surveyed throughout California to identify potentially effective natural enemies of western flower thrips within its presumed evolutionary center-of-origin. Natural enemies recovered from flower bud samples were the parasitic nematode, *Thripinema nicklewoodii* Siddiqui (88.3% of all natural enemies recovered), immature *Orius* sp. (7.1%), at least two species of Acari (4.5%), and 1 species of spider (0.1%). Principle component analysis and multiple regression identified thrips densities as the most important biotic factor correlated with natural enemy densities.

Introduction
Widespread adoption of biological control or IPM as a dominant form of pest control within floricultural crops has been obstructed by the inability of growers to control outbreaks of western flower thrips (WFT), *Frankliniella occidentalis* (Pergande). Severe damage to these crops results from this insect's feeding on flower parts and from its vectoring tomato spotted wilt virus (Robb 1989). Failures to control western flower thrips with up to three insecticide applications per week support the findings reported by Robb (1989) and Immaraju *et al.* (1992) that WFT has developed resistance to a wide range of insecticides. While several predators have successfully controlled thrips on glasshouse grown sweet pepper and cucumber in Europe and Canada (Gilkeson *et al.* 1990, Jacobson 1993), these natural enemies have not provided similar results in floricultural crops (Hessein & Parrella 1990, Smitley 1992).

A central tenet of biological control is that the best natural enemies of a particular pest will be located near the pest's evolutionary center-of-origin. WFT was originally identified as *Euthrips occidentalis* from specimens attacking appricots, oranges and potatoes in California (Pergande 1895). In addition, WFT is the most common species of thrips attacking ornamental plantings in the United States and Canada (Robb 1990). These lines of evidence suggest that the evolutionary center-of-origin of WFT may be in California, and hence, it is possible that the most effective natural enemies against WFT are also located in California. To discover these natural enemies, we conducted a survey of the natural enemy fauna attacking WFT in three major cut-flower commodities; carnations, chrysanthemums and roses.

Materials and Methods
Three major cut flower-production regions of California (San Diego, Santa Barbara, and Monterey counties) were sampled in November 1993 and in March, June and October 1994. The three counties included in the study represent a north-south cline through the coastal portion of the state. Within each county, samples were collected from two greenhouse and two field rose, chrysanthemum and carnation operations according to their availability. A sample consisted of 10 flower buds with flower color just starting to show between the sepals. No more than 5 cultivars from each species were sampled from each operation and an effort was made to keep plant cultivars consistent across sampling localities. Samples collected in

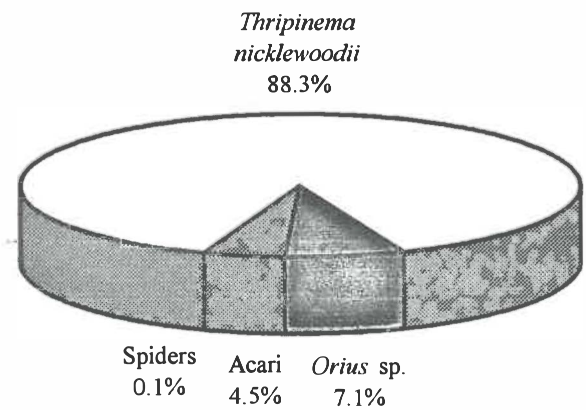
the field were stored in 50% EtOH for transport to laboratory facilities for analysis. All of the arthropods were extracted from the flower buds and stored in saline solution at 2.2°C. WFT were dissected to detect the presence of internal parasites and parasitoids, and all natural enemies were identified to species where possible.

The successful implementation of biological control relies on the ability of agriculturists to modify an agroecosystem to make it (1) less favorable to the pests, and (2) more favorable to their natural enemies. Before a natural enemy is targeted for use in a biological control program, an understanding of the factors influencing its abundance and distribution is necessary. A portion of this study focuses on this problem by examining the patterns of natural enemy abundance and their association with various environmental factors including: season (sample date), geographical location (counties and locations within counties), host plant (or crop), crop phenotype (flower color), and host (WFT) density. Our intent was to use regression techniques as the primary methodology for quantifying the influences of these various environmental factors (the independent variables) on natural enemy abundances (the dependent variables). However, to avoid potential difficulties due to suspected high intercorrelations among these independent variables a principle components analysis was first performed (StatSoft 1993). Principle components analysis creates a reduced number of mathematically independent variables or factors, described by factor loading values. The regression between these new independent variables and natual enemy abundances that maximized the coefficient of determination (r^2) and that was explainable by biological phenomenon was computed using automated curve fitting software (Jandel Scientific 1992). The objective of this procedure was to obtain a small set of independent variables (interpretable as environmental characteristics) which account for as much of the variation in the dependent variable (natural enemy abundance) as possible.

Results and Discussion

A total of 4200 flower buds sampled during the survey yielded 1123 WFT, 572 of which were parasitized by nematode *Thripinema nicklewoodii* Siddiqi, and 76 of the flower buds contained at least one thrips predator (the composition of which are illustrated below).

Composition of WFT Natural Enemies



Natural enemies were collected from all host plants (carnation, chrysanthemum and rose), in all habitats (greenhouse and field), and during each sample data. To identify key factors limiting potentially limiting the abundances of natural enemies, principle componenent and regression analyses were used to identify factors correlated with natural enemy abundances.

The principle component analysis generated two factors that explain 51.1% of the variance among the 7 variables (Table 1). These factors are represented by an original variable or set of variables conservatively identified by factor loadings greater than or equal to |0.7|. The magnitude of the factor loadings indicate the relative importance of each variable to the identity of the principle component factor, the greater the weighting value the more important the variable to the factor. The signs associated with each value represent the relationships among values and influence the sign of the regression coeffiecients. For example, factor 1 explains 29.8% of the variance within the data and consists of the county and location within a county from which samples were collected. Factor 2 explains 21.3% of the variance and consists primarily by WFT densities, followed closely by crop and habitat type.

Table 1. Factor loadings obtained for each principal component and the resulting total variance explained by each principal component. Variables receiving a loading factor ≥ |0.7| with each principal component are followed by an (*).

	----- Variables -----							
Factor	Date	County	Habitat	Location	Crop	Color	WFT	Variance Explained
1	0.029	-0.977*	0.436	-0.966*	0.083	-0.032	0.042	29.8%
2	-0.229	0.002	-0.635	0.051	0.666	0.224	0.736*	21.3%

The automated curve-fitting process tested 453,697,195 linear and 170 non linear equations to maximize the r^2 between principle component derived independent variables and natual enemy abundances. The best fit equations for *T. nickelwoodii* and WFT predators as dependent variables are given in Table 2. Neither equation included factor 1 as a significant independent variable suggesting that geographical location was of little importance to natural enemy abundances. *T. nickelwoodii* exhibited a positive exponential relationship with factor 2, and thus indicated that nematode densities were positively correlated with WFT densities, nematode densities were significantly greater in field compared to greenhouse situations, and nematode densities were significantly greater in carnations, followed by roses and chrysanthemus. WFT predators exhibited no relationship with factor 2, and thus indicated that predator densities were independent of WFT densities, habitat, and crop.

In our study, *T. nickelwoodii* exhibited a positive association with WFT densities whereas the various predators exhibit no association with WFT densities. This pattern could be interpreted to mean the indigenous WFT natural enemies of California ornamentals do not regulate thrips populations. However, the intensive use of insecticides applied to both the greenhouse- and field-grown crops may prevent detection of population regulation . Further, of the 434 parasitized female thrips recovered, only 3 individuals were observed to have mature egges versus the 98% of nonparasitized individuals with mature eggs. Another possible explanation is that *T. nickelwoodii* reponds rapidly to small changes in WFT densities whereas predators respond only to changes of much greater magnitude. Replicated field experiments will be necessary to test these various hypotheses.

Table 2. Results of automated curve fitting procedure set to maximize r^2 obtained from the regression of factors 1 and 2 against *T. nickelwoodii* and WFT predator densities.

Dependent Variable	"Best-Fit" Equation	Variance Explained (r^2)
T. nickelwoodii	$z = 1.2 + 1.6(\text{factor 2})^2 - 0.9\exp^{-(\text{factor 2})}$	0.769
WFT predators	$z = 0.2 + 0.3(\text{factor 2}) - 0.02(\text{factor 2})^3$	0.051

Acknowledgements
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Greenhouse Trials of *Eretmocerus californicus* Howard (Hymenoptera: Aphelinidae) for Control of *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleyrodidae) on Poinsettia in Northeastern U.S.A.

Mark S. Hoddle[1], Roy Van Driesche[1], and John Sanderson[2]
[1]Dept. of Entomology, University of Massachusetts, Amherst, MA 01003, U.S.A. [2]Dept. of Entomology, Cornell University, Ithaca, NY 14853, U.S.A.

1.0 Abstract

The ability of the parasitoid *Eretmocerus californicus* at two different release rates to control silverleaf whitefly (SLW) on poinsettia was determined in experimental greenhouses at Cornell University. Lifetable analysis and weekly population counts of SLW nymphs and pupae indicate that the high release rate of 3 female *E. californicus*/plant/week provides better control (99% mortality of SLW nymphs and 7% parasitism) than a low release rate of 1 female *E. californicus*/plant/week (84% mortality of SLW nymphs and 32% parasitism) until week 14 of the crop cycle. At week 14 the number of live nymphs in the low release greenhouse decreased to levels lower than that observed in the high release greenhouse. The decline in SLW nymphs and pupae may be attributable to the higher levels of parasitism that were observed in the low release greenhouse.

2.0 Introduction

The primary phytophagous pest affecting poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) in the northeastern United States is the silverleaf whitefly (SLW), *Bemisia argentifolii* Bellows & Perring [= the 'B' strain of *Bemisia tabaci* (Gennadius)] (Homoptera: Aleyrodidae) (Perring *et al.* 1991, Bellows *et al.* 1994).

The University of Massachusetts Cooperative Extension System for floricultural crops has initiated an integrated pest management program (IPM) to more effectively manage *B. argentifolii* on poinsettia. One objective of the IPM program is to reduce insecticide use by using biological control agents, in particular, parasitic wasps for suppression of *B. argentifolii*. One of the parasitoids that has been considered for use in the IPM program is *Eretmocerus californicus* Howard. This parasitoid is commercially available. We have evaluated the ability of *E. californicus* at two different release rates, to control SLW on poinsettia in experimental greenhouses at Cornell University, Ithaca, New York. The results of these trials are presented here.

3.0 Materials and Methods

3.1 The experimental greenhouses at Cornell University.

Five small greenhouses (3m x 5m) were used. Each was equipped with six benches which held fifteen 15cm diam. pots per bench. The poinsettia cultivar grown was 'Freedom" and was subject to commercial growing practices. One greenhouse served as an unreplicated control house (no parasitoid releases were made). Two greenhouses received 1 female *E. californicus*/plant/week (low release rate) and two greenhouses received 3 female *E. californicus*/plant/week (high release rate). The trial ran for 14 weeks.

3.2 Constructing lifetables and making population counts.

To evaluate the efficacy of *E. californicus* we constructed lifetables from repeatedly observed cohorts of SLW nymphs (photographed twice weekly). In addition, SLW population counts were made weekly in all greenhouses. Cohorts were established by clip caging 2-3 mating pairs of whiteflies on a poinsettia leaf for 36-48 hours. After this time the adults were aspirated and the eggs counted using a stereomicroscope. The number of eggs per leaf ranged from 3-45 and the number of plants used in each greenhouse ranged from 8-15. The number of eggs introduced were manipulated to ensure each greenhouse received similar numbers of eggs. Plants on which cohorts were established for photography were flagged and numbered. The leaf with the cohort to be photographed was numbered. As soon as the crawlers emerged and settled, the exact section of the leaf that was to be photographed was delineated using an indelible marker to define a 3.5cm x 2.3cm area within which cohort members were located. A small label (4mm x 3mm) with an identifying number was affixed within the marked perimeter. The delineated area was photographed twice a week. Photography of the cohorts continued until all nymphs had emerged as adult whiteflies, produced an adult parasitoid, or died. Cohorts were established as detailed above at weeks 1, 2, 6 and 11 of the trial.

Photographic slides were examined under a back lit stereomicroscope. A map of the leaf was drawn for each photographic date and individual nymphs were plotted on the map. The fate (i.e., whether the nymph emerged as an adult whitefly, died from natural causes, host feeding, parasitism or disappeared) for each photographed nymph was determined for each photographic session and recorded on the map.

To estimate the changes in population density of whiteflies, weekly population counts were made in each greenhouse. At week one of the trial, 15 randomly selected plants were flagged and one leaf was numbered. The marked leaf was examined every week and the number of live and dead first and second instars, third instars, fourth instars, and pupae were recorded along with the number of pupal cases from which whiteflies or parasitoids had emerged. In addition to this, counts of adult whiteflies were made. In each greenhouse 30 randomly selected plants had one leaf examined, and the number of adult whiteflies on the leaf were recorded. An additional 15 plants were chosen for immature SLW population counts in each of week 6 and 11, such that 45 plants and 45 leaves were inspected in each greenhouse at week 11 and thereafter. An additional leaf on each of the 30 randomly selected plants was added to the leaves inspected for adult SLW at week 6 and 11 to give a total of 90 leaves on 30 plants by week 11.

4.0 Results

The results presented below are for one greenhouse for each of the three treatments.

4.1 Lifetables

In the absence of parasitoids, 75% of the eggs laid on poinsettia leaves produced adult whiteflies. When *E. californicus* was released at a rate of 1 female/plant/week, egg to adult mortality was 84% and 32% parasitism was observed. A release rate of 3 female *E. californicus*/plant/week achieved 99% mortality and 7% parasitism (Table 1).

Table 1. Partial lifetables for one greenhouse for each of the three treatments.

Stage	Control Greenhouse	1 female/pl/wk	3 females/pl/wk
Eggs	1068	757	847
Nymphs	951	658	770
Adults	861	126	10
% mortality	25%	84%	99%
% parasitism	—	32%	7%

4.2 Population Counts

In the absence of parasitoids, SLW population growth for nymphs and pupae exhibited exponential growth which accelerated after week 11 (Fig. 1). A release rate of 1 female *E. californicus*/pl/wk suppressed whitefly population growth when compared to the control house (Fig. 2) but not as efficiently as a release rate of three female *E. californicus*/pl/wk, where the number of live nymphs and pupae were lower until week 14 of the trial (Fig. 3).

The number of dead nymphs accumulating on leaves increased steadily in both greenhouses receiving parasitoids (Figs. 2 and 3). The levels of observed mortality in the weekly population counts was higher in the greenhouse receiving 3 females/pl/wk. A low level of parasitism was detected in the greenhouse receiving 1 female/pl/wk after week 10 of the trial (Fig. 2). Parasitism was not observed on the leaves that were inspected weekly in the greenhouse receiving 3 females/pl/wk (Fig. 3).

5.0 Discussion

A release rate of 3 female *E. californicus*/pl/wk provides better control of SLW on poinsettia than a release rate of 1 female *E. californicus*/pl/wk. This is seen in the lifetables in which the higher release rate achieved 99% mortality, while the lower release rate resulted in 84% mortality. Whitefly population growth is more effectively suppressed in the greenhouse receiving 3 female *E. californicus*/pl/wk when compared to the greenhouse receiving 1 female/pl/wk. However, at week 14 of the crop cycle the whitefly population in the low release house declined, which was not the case in the high release rate greenhouse. The observed population decline may be attributable to higher levels of within-house reproduction by *E. californicus* at the low release rate (32% parasitism in cohorts compared to 7% parasitism in the high release rate greenhouse). Parasitoid recycling via reproduction in the low release rate greenhouse may have augmented weekly parasitoid releases thereby resulting in a population decline of live SLW nymphs and pupae at week 14.

At a higher release rate, lower levels of parasitism occurred because large numbers of susceptible nymphs died from host feeding or superparasitism. We suspect that this occurred because of the higher density of searching female parasitoids. At the low parasitoid release rate more parasitized nymphs survived. The SLW nymph population increased steadily from week 12 in the high release greenhouse. There are two possible reasons for this. The first is that within-house recycling was low as detailed above. The second is the possibility that searching females were diluted over larger canopy volumes as the plants grew. This may have resulted in more whiteflies escaping attack because they were harder to find.

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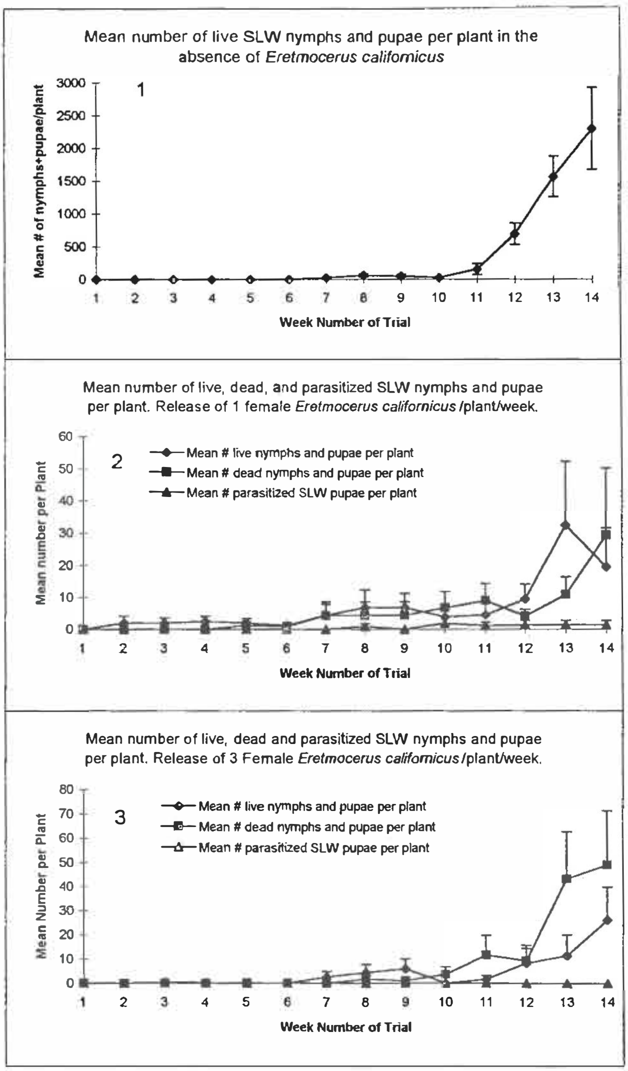

BIOLOGICAL CONTROL OF WESTERN FLOWER THRIPS ON CUCUMBER USING THE PREDATORY MITES *AMBLYSEIUS CUCUMERIS* AND *A. LIMONICUS*

Yvonne M. van Houten
Research Station for Floriculture and Glasshouse Vegetables, P.O. Box 8, 2670 AA Naaldwijk, The Netherlands

Abstract
The phytoseiid predators *Amblyseius cucumeris* and *A. limonicus* were evaluated as biological control agents of Western Flower Thrips, *Frankliniella occidentalis,* on greenhouse-grown cucumber. The results of experiments in the period of July till October showed that both predators got established in the crop. The impact on thrips populations throughout the season was greater for *A. limonicus* than for *A. cucumeris*, and specific characteristics enabling successful control are discussed.

Introduction
Western Flower Thrips, *Frankliniella occidentalis* (Pergande), is a major pest in greenhouse grown cucumbers in the Netherlands. It can cause direct damage by feeding on developing fruits resulting in heavy scarring and fruit malformation, and indirect damage by feeding on leaves. Chemical control interferes with biological control of other pests. Therefore, an effective biological control agent of *F. occidentalis* is needed.
At present, the predatory mite *Amblyseius cucumeris* (Oudemans) is used for biological control of *F. occidentalis.* Its success in thrips control, however, is often unpredictable and high numbers of predatory mites have to be introduced throughout the growing season. In search for a thrips predator that could improve biological control, Van Houten *et al.* (1995a) compared 7 species of phytoseiid predators of thrips with respect to a number of features relevant for biological control. The results of this laboratory study showed that *Amblyseius limonicus s.s.* Garman and McGregor is a promising candidate for thrips control under high-humidity conditions. In Dutch greenhouses humidity levels decrease during frost periods and on bright days in summer, when ambient temperature is high. The eggs of *A. limonicus* are very sensitive to low air humidity which indicates that drops in humidity levels might reduce the effectiveness of *A. limonicus* as control agent. Van Houten & Van Lier (1996), however, reported that in a healthy cucumber crop the survival of eggs and larvae of *A. limonicus* are only moderately influenced by low air humidity conditions in Dutch greenhouses.
In the present study *A. cucumeris* and *A. limonicus* are compared with respect to their establishment and efficacy of controlling western flower thrips on cucumber during the period July till October.

Materials and Methods
The non-diapause strain of *A. cucumeris* used originated from the strain collected in New Zealand, in 1991 (Van Houten *et al.*, 1995b). *Amblyseius limonicus* was collected from cucumber near Auckland, New Zealand, in 1991. Both species were kept in incubators under long-day illumination (L16:D8) at 25°C and 75% RH. The mites were reared on rectangles of black plastic (8 x 15 cm), placed on soaked cotton wool. The cultures of *A. cucumeris* were fed with commercially available pollen of different plant species,

collected by honey bees. The cultures of *A. limonicus* were fed with pollen of the broad bean (*Vicia faba* L.)
The experiments were carried out at the Research Station for Floriculture and Glasshouse Vegetables (Naaldwijk, The Netherlands) in a small greenhouse of 76 m^2 with 12 rows of 9 cucumber plants (var. Aramon).
Amblyseius cucumeris was released on plants in 6 rows on one side of the greenhouse whereas *A. limonicus* was released on the plants in the other 6 rows. In week 30, when the plants were 6 weeks old, 8 female predators were introduced per plant. At this moment the crop was lightly infested with thrips. To monitor the thrips and predator populations, samples of 18 leaves per treatment were taken in week 32, 35 and 38. For these countings the sixth mature leaf from the growing tip was chosen because in earlier experiments thrips larvae and predators were most numerous on these leaves (unpublished results). Spider mite and white fly were controlled with commercially obtained *Phytoseiulus persimilis* and *Encarsia formosa*, respectively. Aphids were controlled with open rearings of *Aphidius colemani* on *Rhopalosiphum padi* with wheat as a host plant (Van Steenis, 1996).

Results and Discussion

Establishment of the thrips predators

Amblyseius cucumeris and *A. limonicus* were introduced successfully and their populations persisted (Figs. 1, 2). *Amblyseius limonicus* performed best; the predator population increased more rapidly and reached (mean and peak) higher density than *A. cucumeris.* In the present study the adult thrips population increased to high density in the whole greenhouse (unpublished results)). This implies that high numbers of thrips larvae are available as a food source on the leaves in both the *A. cucumeris* and *A. limonicus* plot. Laboratory experiments have shown that *A. limonicus* exhibited a higher peak oviposition rate on a diet of thrips larvae than *A. cucumeris* (Van Houten *et al.*, 1995a). The presence of an ample amount of prey and the high oviposition rate of *A. limonicus* may partly explain the success of this species.

Impact of the predators on the thrips populations

Amblyseius cucumeris was not able to control the thrips (Fig 1). In the *A. cucumeris* plot, the thrips population increased to 130 thrips larvae per leaf in week 38. *Amblyseius limonicus* was more successful in thrips control in this study. The thrips population increased to 11 thrips larvae per leaf in week 35, then decreased to 5 larvae per leaf in week 38 (Fig 2). The success of *A. limonicus* may partly be explained by the predation rate. Laboratory experiments showed that *A. limonicus* exhibited in comparison with *A. cucumeris* a higher predation rate when fed on first- and second-instar thrips larvae (Van Houten *et al.*, 1993, 1995a). Besides, in the present study it was observed that *A. limonicus* showed a higher locomotory activity on plants than *A. cucumeris.* This could lead to an increased encounter rate of the mites with thrips larvae and hence to higher thrips mortality.
Based on these results, *A. limonicus* can be regarded as a promising control agent of thrips on greenhouse grown cucumber. More greenhouse trials have to be performed to find out if *A. limonicus* is able to control thrips infestations year-round. A mass-rearing technique for *A. limonicus* has still to be developed.

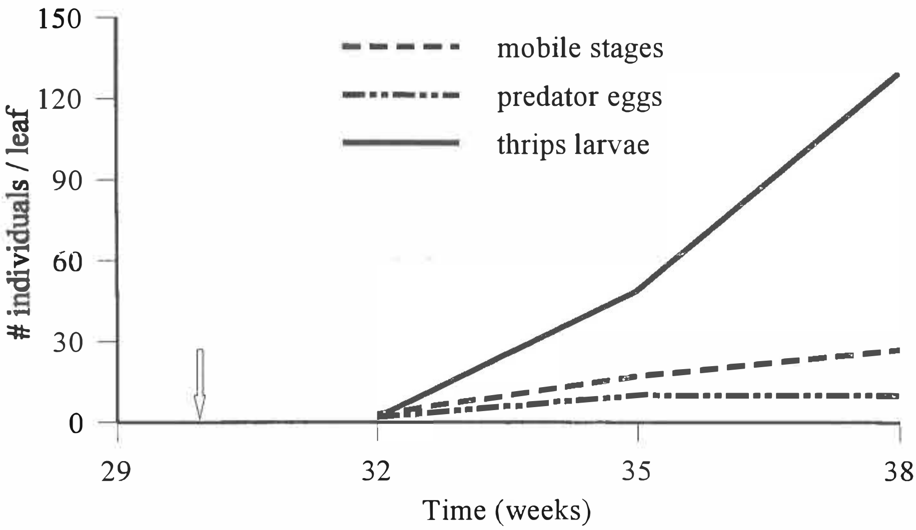

Figure 1. Mean number of *A. cucumeris* and *F. occidentalis* on leaves of cucumber. Arrow indicates release of 8 predatory females per plant.

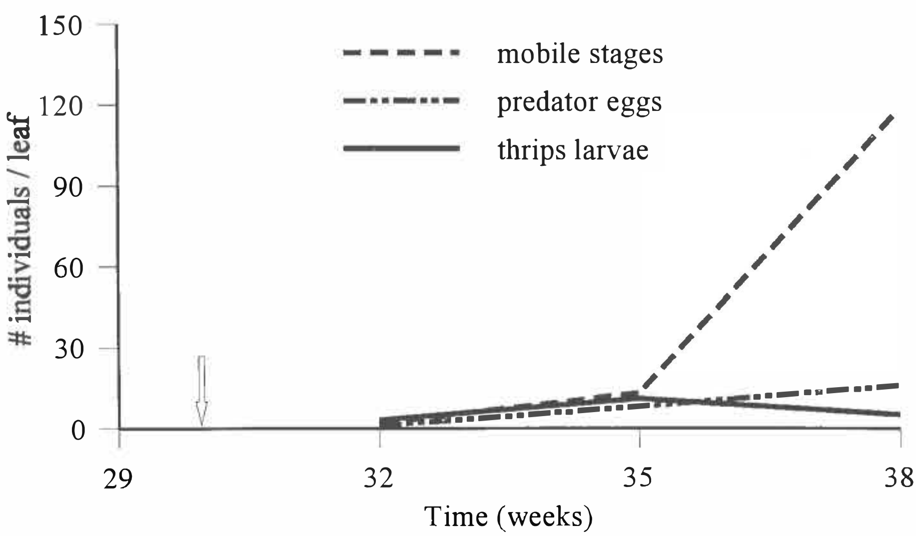

Figure 2. Mean number of *A. limonicus* and *F. occidentalis* on leaves of cucumber. Arrow indicates release of 8 predatory females per plant.

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IMPLEMENTATION OF IPM IN HUNGARIAN GREENHOUSES

ZOLTÁN ILOVAI, CSABA BUDAI, ERZSÉBET DORMANNS-SIMON, EDIT F. KISS
Biological Control Laboratory, Csongrád County Plant Health and Soil Conservation Station
Hódmezővásárhely, 6801 P.O.Box 99. Hungary

Abstract

The paper draws attention to the particularities of greenhouse growing. In addition to production structure and technical problems it shows the circle of newly appeared and spread pests, calls attention to soil-borne diseases, on the importance of virus diseases and control of their vectors. In integrated systems beside biological regulations it is necessary to introduce alternative control methods preventing virus infections.

Introduction

Protected crops are grown in Hungary on about 6000 hectars. From this the rate of modern, large-scale glasshouses is about 300 hectars. In greenhouse growing the vegetables are overwhelming. In heated circumstances capsicum and cucumber are dominating. Unheated greenhouse growing is significant (60 %), mainly in plastic tunnels and blocs.
Because of the change of economical system in Hungary, the rate of small-size (below 500 m^2) farms has increased. The technological development is suppressed by the low level of capital concentration. Specialization became common in large greenhouse farms. On the contrary, in small-scale family farms growing of several crops is characteristic. Often they grow together ornamentals and vegetables, and greenhouse growing is often supplemented with open-field growing. In pest management chemical control is dominating but the use of selective and specific pesticides has increased. Introduction of biological pollination has given a significant impulse to spreading and success of biological control.

Pest and disease problems

The circle of general pests has further increased. From among sucking pests *Bemisia tabaci* and *Frankliniella occidentalis* were introduced (1989-1990). The consequence of this was that the rate of biological control decreased or stagnated (40-50 ha/year). The necessity of chemical control was determining. This could be explained by the increasing occurrence of virus diseases the reason of what was the pesticide resistance of virus vector insect pests see Table 1.).
Helicoverpa armigera has been spreading with considerable speed since 1995, this way creating totally new situation in tomato and capsicum, so further chemical intervention became necessary. Besides damage to vegetative parts the damage to fruits has become significant.
The following species of root-knot nematodes have so far been reported to occur in Hungary: *Meloidogyne incognita, M. arenaria, M. hapla, M. javanica, M. incognita acrita, M. thamesi and M. naasi.* There are 10 specific nematicides registered for nematode control in Hungary. These chemicals are mainly applied in glasshouses where their use produces the most economical return. Nematode-resistant cultivars are only available in the case of tomato. There are other control possibilities applied like isolated growing, change of crops, soil-steaming, exposing to winter frost, fumigation, and using of systemic insecticid-nematicides.

Table 1.

Most important virus diseases of vegetables in Hungary

Transmission	**Virus name**	**Family/Group**	**Acronym**	**Crop (importance)***
soil/seed/mechanical	Tobacco mosaic	TOBAMO	TMV	pepper(+++) tomato(+++)
	Tomato mosaic	TOBAMO	ToMv	pepper(+++) tomato(+++)
	Pepper mild mottle	TOBAMO	PMMV	pepper(o)
by soil fungi	Pepper yellow vein	?	PYVV	pepper (o)
by aphids	Cucumber mosaic	CUCUMO	CMV	pepper (+++) tomato (+++) cucumber (+++)
	Potato virus Y	POTY	PVY	pepper (++) tomato (++)
	Alfalfa mosaic	AMV	AMV	pepper (++)
	Tomato aspermy	CUCUMO	TAV	pepper (+)
	Broad bean wilt	COMO	BBWV	pepper (+)
by thripses	Tomato spotted wilt	TOSPO	TSWV	pepper (o) tomato (o)
by whiteflies	Tomato yellows	GEMINI	?	tomato (?)
	Cucumber yellows	GEMINI and ?	?	cucumber (?)

Legend * : (+++) widely spread since long time, presently also very important
(++) widely spread since long time, presently less important
(+) appeared long ago, lately is diminishing
(o) appeared in latest years, gets spreading
(?) symptoms of the disease appeared in latest years, identification of the virus is going on

Greenhouse growing in Hungary goes on natural soil, commonly with manure based fertilisation supplemented with fertigation and overhead fertilization. The spreading habit of growing long-vegetation crops, the regular change of cool and warm periods seem to favour to wilt diseases like *Fusarium spp.* and *Verticillium spp.*. Diseases like *Botrytis cinerea, Sclerotinia spp*and the damping-off diseases (*Rhizoctonia solani, Alternaria spp.* and *Pythium spp.)* in seedling age are also very common. Physical and chemical methods of soil desinfection are still dominating, though in Hungary biological and alternative means of control of pathogens are getting to be available (see Table 2.).
Besides registering biopesticides, soil conditioning with composts is also feasible; this way the antagonists could prevail in the soil.

Table 2.

Biological and alternative control possibilities against diseases of greenhouse crops in Hungary

Diseases	Main host plants	Control agents
Sclerotinia spp.	paprika lettuce cucumber	Coniothyrium minitans (Micon[1])
Botrytis cinerea	paprika tomato lettuce cucumber	Trichoderma spp.[2] Trichoderma harzianum (Trichodex WP[3])
Fusarium spp.	paprika tomato carnation gerbera	Streptomyces griseoviridis (Mycostop[4])
Damping-off diseases (Rhizoctonia, Alternaria, Pythium, etc.)	all greenhouse crops	Streptomyces griseoviridis (Mycostop)
Powdery mildew (Erysiphe spp., Sphaerotheca fuliginea, Leveillula taurica)	cucumber tomato paprika	Ampelomyces quisqualis[5] Vektafid A[6]

Implementation of IPM

Reinforcement of biological control

Main barrier of development and introduction of biological control methods is the lack of natural enemies of introduced new pests. Therefore adaptation of bioproducts developed elsewhere and incorporation of them into pest management is important. Presently only Encarsia formosa is officially on sale from among more than 30 kinds of products. Introduction of predatory mites is inhibited by the high level of costs. Multiplication of locally found parasites and predators in natural circumstances has minor chances, though in case of native *Miridae* it is promising. Application of aphid parasites by the help of "banker" method

[1] Biopreparate of Plant Protection Research Institute of Hungarian Academy of Sciences (dr László Vajna), in experimental stage, not yet registered

[2] There are standard Trichoderma preparates developed by the Hungarian plant protection network, but they are not registered and not manufactured because of the lack of sponsors

[3] Preparate of Makteshim Chemical Works Ltd. (Israel) registered in Hungary

[4] Preparate of Kemira Oy (Finland) registered in Hungary

[5] Experimental preparate of Plant Protection Research Institute of Hungarian Academy of Sciences (dr L.Vajna, dr Levente Kiss)

[6] Alternative preparate of Chemark Ltd (Hungary) based on light summer oils

has not yet began. Against nematodes and diseases the solarization and introduction of nematophagous fungi (Arthrobotrys oligospora) is a near-future possibility. Efforts must be taken for the introduction of Bacillus thuringiensis products in greenhouses.

Decreasing and reform of chemical control

In greenhouse growing the revision of pesticides and termination of the use of those pesticides what are persistent and toxic for beneficials, is urgent (taking into consideration the IOBC categories). Improving of application technics could decrease the pesticide quantity too, the same way as wide spreading of the utilisation of smokes, fogging, ultra-low volume spraying, different effect-boosters, surfactants, evaporation reducers,etc.

Prevention methods

Plant protection supervision concerning export-import is well established. Now it is necessary to harmonize the production and circulation of seeds and propagating materials with the European normes. There are plans to indroduce "plant passport", to standardise the production and to introduce trade marks. The integration of the production should be extended to growing substrates, irrigation water, climatization, storage and transport. Alternative control methods (hygiene, resistant varieties, isolation, different traps - smell, pheromone, colour, etc. - should serve the purpose of decreasing the use of chemical control.

Main IPM strategical elements in the future

1. Further decreasing the chances of widespread use of pesticides. The pesticide decreasing programme should at first be started in vegetables.
2. Application of different forms of state support for introduction of biological and non-chemical methods. Registration of biological pesticides should be free of of charges
3. Acceleration of the introduction of registered and available biological agents in modern, climatized greenhouses. Integrated modell demonstration trials should be organized in European projects, and international cooperation programmes
4. In traditional and non-heated greenhouses development and spreading and practical study of control methods supporting the native beneficials and prevention.
5. Organization of integrated pest management courses for growers and specialists

Research and development of biological control reached such level in case of several pests and diseases it is already able to substitute the chemical methods! This is helped by the work of biopesticide (bioagent) producers and traders.

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Control of glasshouse leafhopper (*Hauptidia maroccana*: Homoptera, Cicadellidae) within an IPM programme in protected tomatoes.

R. J. Jacobson[1] and R. J. Chambers[2]
[1]HRI, Stockbridge House, Cawood, Yorks, YO8 OTZ, UK
[2]HRI, Efford, Lymington, Hants, SO41 OLZ, UK

Abstract
The leafhopper, *Hauptidia maroccana*, is becoming an increasingly important pest in UK tomato crops. It may be controlled with heptenohos but this disrupts IPM and biological pollination. Cost-effective, integratable control measures are urgently required. These experiments furthered the development of a control strategy based on a combination of the insect growth regulator, buprofezin, and the egg parasitoid, *Anagrus atomus*. A single application of buprofezin in late January provided acceptable control until mid-April, thus reducing the dependence on the parasitoid until later in the season when it is most effective. The studies also took into account secondary benefits of the buprofezin treatments on the control of *Trialeurodes vaporariorum*. Savings from delayed release of the parasitoid, *Encarsia formosa*, covered the cost of the buprofezin treatment.

Introduction
The leafhopper, *Hauptidia maroccana* (Melichar), has been a sporadic pest of tomatoes in the south of England for the last decade and recent outbreaks in the north suggest it is becoming more important. It may be controlled with heptenophos, but this insecticide disrupts integrated pest management (IPM) of other pests and adversely affects biological pollination by bumble bees.

In previous studies, the egg parasitoid, *Anagrus atomus* (L.), has given encouraging control of this pest even at low introduction rates (Helyer, pers comm; Cooper, 1993). However, it has been inconsistent, particularly in the early season, and a more reliable control measure is required to support it.

The insect growth regulator, buprofezin, marketed in the UK as Applaud for control of glasshouse whitefly, *Trialeurodes vaporariorum* (Westwood), has been shown in laboratory experiments to interfere with the development of *H. maroccana* (Helyer, pers comm). The chemical only has activity against a narrow range of insects and will integrate with most biological control agents in the IPM programme.

This experiment assessed three buprofezin treatment programmes for the control of *H. maroccana* in a glasshouse environment. It also took into account secondary benefits on the control of *T. vaporariorum* by testing revised control strategies in which introductions of the parasitoid, *Encarsia formosa* (Gahan) were delayed. The financial implications of the modified IPM programme were also evaluated.

Materials and Methods
Location: HRI, Efford, Lymington, Hants, SO41 OLZ, UK.
Cultivar: Pronto.
Substrate: Plants grown hydroponically on rockwool slabs, excess feed to waste.
Planting date: 12 December (wk 50) 1994.
Training system: "V" system. Additional side shoots taken in wks 2 and 9 of 1995, increasing the shoot density to approx. 27000 and 33800 per hectare respectively.
Pest infestations: 55 adult leafhoppers released in each compartment over three occasions

in wks 51 and 52 of 1994 and wk 1 of 1995. 150 adult whiteflies released in each compartment over three occasions in wk 51 of 1994 and wks 1 and 2 of 1995.
Experimental design: Twelve glasshouse compartments, each of 63 m^2, in two linear blocks of six. Four treatments, replicated three times in separate compartments.
Treatments: T1. Untreated control.
T2. One application of buprofezin in wk 4, 1995.
T3. Two applications of buprofezin in wks 4 and 5, 1995.
T4. Two applications of buprofezin in wks 4 and 6, 1995.
Buprofezin applications: Buprofezin was applied as a high volume spray to run off at the recommended rate of 30 ml product per 100 l water.
Encarsia introductions: One parasitised scale per tomato stem from wk 5 1995 in the untreated controls and from wk 12 1995 in other treatments. The rate was increased in the T1's during the latter stages in an attempt to control the rapid whitefly development.
Assessments dates: All treatments sampled prior to first application of buprofezin in wk 4 1995, and then at fortnightly intervals until wk 18 1995 (T1 omitted in wk 18).
Assessment procedure: Thirty plants were marked in each compartment. On each assessment date two leaves (approx 0.5 and 1.8 m from ground) were selected on each marked plant for examination. The percentage leaf area damaged by leafhoppers, the numbers of leafhopper adults and nymphs, and the numbers of unparasitised and parasitised whitefly scales were recorded.
Analysis of results: Separate analyses of variance were done at each assessment date.

Results

Leafhoppers

The mean numbers of leafhoppers per leaf and the loss of leaf area due to leafhopper feeding are summarised in figures 1 and 2 respectively. The numbers of leafhoppers were small and similar in all treatments for four weeks after application of buprofezin. The population in the untreated controls (T1) then began to increase, exceeding 10 per leaf at 12 weeks. In T2, which received a single application of buprofezin, the numbers began to increase 10 weeks after treatment and thereafter increased at a rate comparable to T1. Where two sprays were applied (T3 and T4), the population increase was delayed by a further one to two wks but then developed at a rate similar to T1 and T2. Feeding damage paralleled the pattern of population growth throughout the experiment.

Whiteflies

The mean numbers of unparasitised and parasitised whitefly scales per leaf are summarised in figures 3 and 4 respectively. The numbers of unparasitised scales were small and similar in all treatments for four weeks after application of buprofezin. The numbers on the untreated controls then rose, reaching over 80 per leaf at 12 weeks. In the treatments which received buprofezin, there were no evidential population increases at 12 weeks but numbers increased slightly to 1.8 per leaf in T2 at 14 weeks. In T1, the number of parasitised scales began to increase eight weeks after treatment and reached 60 per leaf at 12 weeks; that is 43% parasitism. Parasitised scales were detected in the other treatments but the results were difficult to interpret because the overall numbers of scales were so small.

Discussion

Leafhoppers

In crops infested with *H. maroccana* in December, a single application of buprofezin in late January provided acceptable control until mid-April, that is a delay of five to six weeks compared to untreated controls. There was no evidence of any significant cumulative effect from multiple applications of the chemical; serious damage was still only delayed by five to six weeks from the last application.

Buprofezin is harmless to immature *A. atomus* (Helyer, pers comm) and these two control measures should be compatible. The insect growth regulator is also harmless to bumble bees and the majority of biological control agents and should integrate within the tomato IPM programme. However, its effects on the spider mite predator, *Therodiplosis persicae* Keiffer, are not yet known and this must be determined as it could become an important component of the IPM package.

If leafhoppers are present early in the season, a single application of buprofezin will slow down the pests development allowing *A. atomus* a better chance of success. It will reduce dependence on the parasitoid until later in the season when it is known to be more effective. The precise timing and rates of introduction of *A. atomus* are still to be determined but it is anticipated that frequent releases will be required starting about three weeks after the buprofezin treatment.

Whiteflies

A single application of buprofezin delayed the onset of *T. vaporariorum* population growth by over six weeks compared to untreated controls. As with leafhoppers, there was no additional advantage gained from multiple applications of the chemical.

It is not proposed that buprofezin should be used routinely against *T. vaporariorum* because *E. formosa* already provides good control. Indeed, it is sensible to limit its use to essential remedial treatments so that the pest is less likely to develop resistance. However, where buprofezin is required against leafhoppers there will be an opportunity to save money by delaying introductions of *E. formosa*.

Financial Implications

The financial implications of modifying the overall tomato IPM programme have been determined in trials at HRI Stockbridge House. Two whitefly control strategies, which both maintained *T. vaporariorum* infestations at acceptable levels, were evaluated, taking into account the cost of *E. formosa*, Applaud, labour and overheads:

1. Standard *Encarsia* programme - *E. formosa* were introduced at 7500/ha/wk from wk 50 to 15, then at 12500/ha/wk until wk 33. Total cost = £1163/ha.
2. Buprofezin/*Encarsia* programme - One buprofezin application in wk 4, followed by *E. formosa* at 7500/ha/wk from wks 8 to 15, then at 12500/ha/wk until wk 30. Total cost £1175/ha.

It is clear that a single buprofezin treatment against leafhoppers may be integrated into the tomato IPM programme without significantly increasing the overall cost.

Acknowledgements

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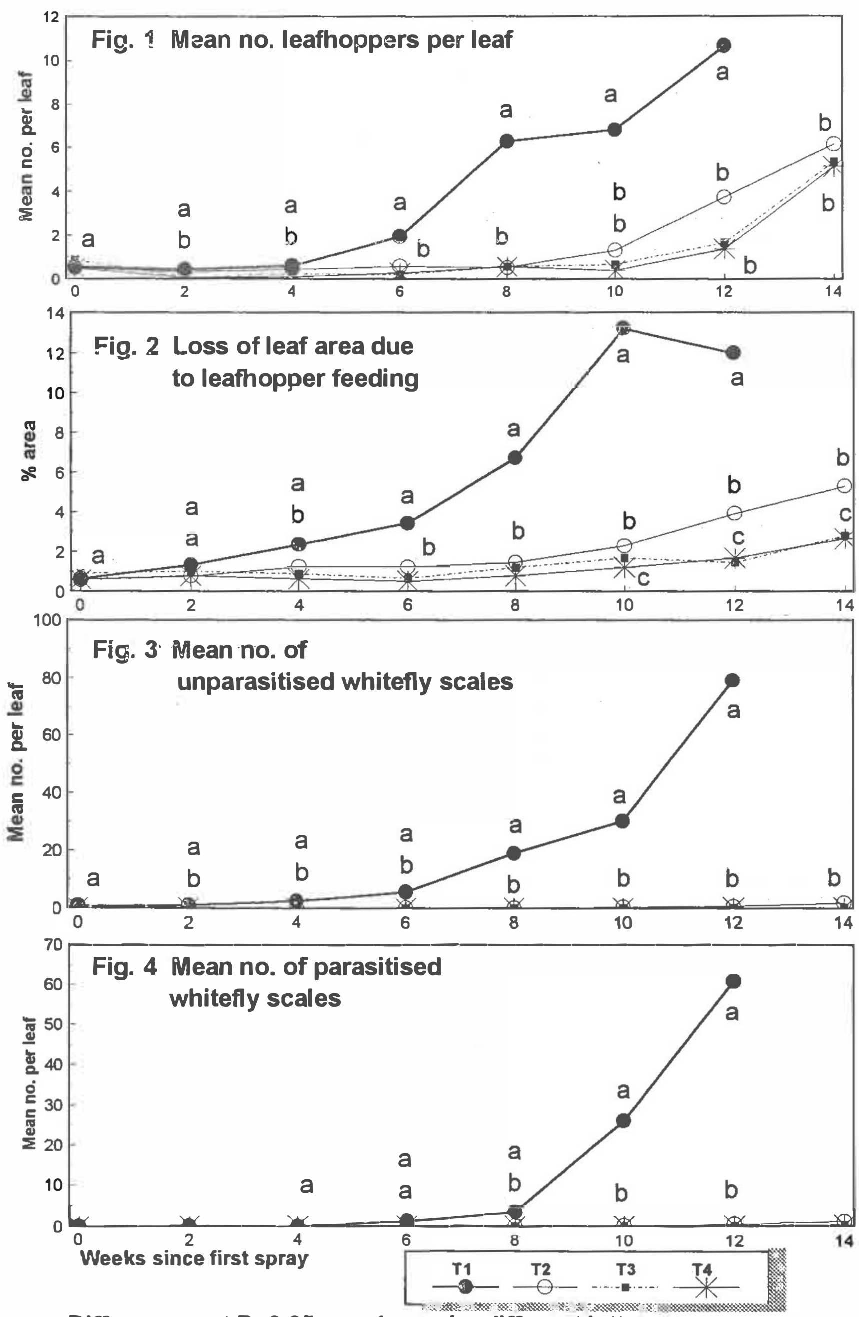

Differences at $P<0.05$ are shown by different letters.
Proximate non-significant points shown by a single letter.

Development of Tetranychus urticae Koch and Tetranychus cinnabarinus Boisd. populations on sweet pepper and Phytoseiulus persimilis (A.- H) effectiveness in their control

Danuta Kropczyńska , Anna Tomczyk

Department of Applied Entomology, Warsaw Agricultural University,
Nowoursynowska166, 02-787 , Warsaw , Poland.

Abstract

Densities of T. urticae and T. cinnabarinus populations developing separately or together on plants of two cultivars of glasshouse sweet pepper - Bendigo and Monica, were compared. It was found that both species could quickly reach high quantities if feeding separately. T. cinnabarinus population showed a similar density on both tested cultivars , whereas T. urticae prevailed on cv. Bendigo. Simultaneous infestation of T. urticae and T. cinnabarinus had a negative effect on the development of the latter. Ph. persimilis effectively controlled both spider mite species, although it seems that some preference towards T. cinnabarinus occurred.

Introduction

Spider mite belongs to the major pest of sweet pepper grown both in glasshouses and outdoors. This crop is most often infested with T. urticae, although in Bulgaria glasshouse sweet pepper is also attacked by T. turkestani (Atanasov 1983) . In Poland, two spider mite species, T. urticae and T. cinnabarinus, were found on sweet pepper grown under glass.
Biological control of spider mites with use of Ph. persimilis, which began in the Netherlands in the 1970s (Woets 1976), is being conducted in many European countries, also in Canada and Australia (Atanasov 1983, Loginova et al. 1987, Altena & Ravensberg 1990, Ravensberg et al. 1993, Baxton et al. 1990, Benuzzi & Nicoli 1993, Sponer-Hart 1993) . In Poland biological control of spider mites on sweet pepper started 4 - 5 years ago and good results are still being observed. However, with no data available, the effectiveness of Ph. persimilis in the control of T. urticae and T. cinnabarinus on sweet pepper could not be compared and this motivated the authors to undertake the present research.

Material and methods

The research was carried out in 1993 and 1994 on two cultivars of glasshouse sweet pepper : Monica and Benigo, grown in rings with garden peat. In each season 15 - 30 plants were used for experiment to examine :

1. Development of T. urticae and T. cinnabarinus populations feeding separately on sweet pepper plants.
20 females of T. urticae or T. cinnabarinus were deposited on each of 15 plants of each cultivar. Number of mobile stages has been repeatedly recorded over a few weeks.

2. Development of mixed populations of T. urticae and T. cinnabarinus on sweet pepper plants.
20 females of T. urticae and 5 females of T. cinnabarinus were deposited on each of 15 plants of each cultivar. For a few weeks the number of specimens within both populations had been recorded on each cultivar.

3. Effectiveness of Ph. persimilis in the control of both spider mite species on sweet pepper plants.
30 plants of each cultivar were used for the experiment. A half of them was initially infested with 20 females of T. urticae per plant, while the other half was analogicaly treated with T. cinnabarinus. The first introduction of Ph. persimilis was performed after 2 and 4 weeks of feeding, for T. urticae and T. cinnabarinus respectively. Each group of the plants was subjected to 3 introductions at weekly intervals, using 20 specimens per plant.

Results and discussion

Figures 1 - 3 present the development of T. urticae and T. cinnabarinus on sweet pepper. After five weeks, both species feeding separately reached almost the same population density on cv Bendigo, whereas cv Monica T. urticae was less numerous / Fig.1 /.
A peculiar development was observed when both species fed together on sweet pepper plants / Fig. 2 and 3 /. In such a case during 6 weeks of simultaneous infestation T. cinnabarinus population almost stopped developing, while T. urticae increased in numbers 7 - fold on cv Monica and over 10 - fold on cv Bendigo, as compared to its initial quantity. At the present stage of research it is difficult to explain such a phenomenon, however, the previous experiments on different host plants also revealed a negative interaction between these species (Tomczyk et al. , in press). In mixed populations on cucumbers and Gerbera T. cinnabarinus was dominant.
The results regarding the effectiveness of biological control of spider mites on sweet pepper are presented in Fig. 4 and 5. Ph. persimilis was found highly efficient in the control of T. cinnabarinus on both cultivars. The first introduction of the predator was performed after 4 weeks of pest feeding, when the density of spider mite population exceeded 700 specimens per plant on both cultivars. Two weeks later, when two introductions were already conducted, the pest population declined to a quater of the previous level. At the time of the third introduction, the density of T. cinnabarinus population was below 200 specimens per plant on both cultivars. Four weeks later, this pest had been totally eliminated from the examined plants.
Fig. 2 presents the effectiveness of Ph. persimilis used for the control of the T. urticae. A week after the first introduction of the predator, the population of this pest on cv Bendigo expanded almost four times, from 150 to 550 specimens per plant. At the same time, T. urticae on cv Monica was less abundant, i.e. around 400 specimens per plant biologically protected and 460 specimens per non-protected plant. The subsequent introduction resulted in a reduction of spider mite population on both cultivars by almost 40 % as compared to the plants without the predator. During the two weeks following the third introduction the population of T. urticae on both cultivars distinctly declined and the number of spider mites on biologically protected plants was more than 10 times lower than on those non- protected.The results of the above experiments revealed a high performance of Ph. persimilis in the control of T. cinnabarinus and T. urticae, although in the case of the first species the predator appeared to be more effective.There is no literature data on the efficiency of Ph. persimilis used for suppression of T. cinnabarinus on sweet pepper. This predator was usually effective if introduced at the very beginning of pest infestation. At that stage the population of spider mites oscillated between 2 - 5 specimens per plant and 2 - 3 specimens per leaf (Baxton et al. 1990, Loginova et al. 1987). According to Atanasov (1983), the introduction of Ph. persimilis performed at a predator-prey ratio of 1 : 10 provides an effective reduction of T. urticae and T. turkestani feeding together on sweet pepper.The test results presented on Fig. 4 suggested a higher effectiveness of Ph persimilis towards T. cinnabarinus as compared to T. urticae and T. turkestani infesting sweet pepper. Although the first introduction was conducted at a predatory-prey ratio of 1 : 35, the population of T. cinnabarinus declined in a very short time.

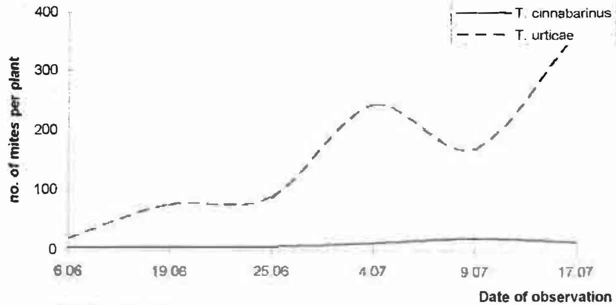

FIG 3 . Development of spider mite populations on sweet pepper cv. Bendigo

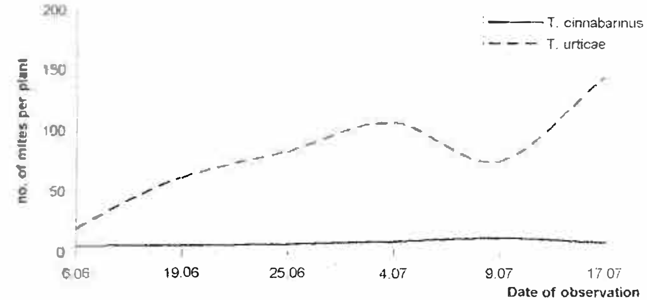

FIG 2 . Development of spider mite population on sweet pepper cv. Monica

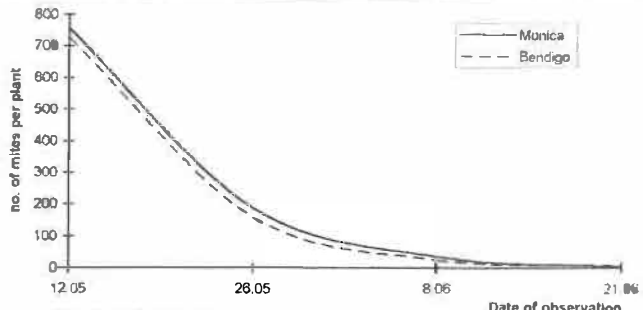

FIG 4 . Effectiveness of Ph. persimilis in control of T. cinnabarinus on sweet pepper

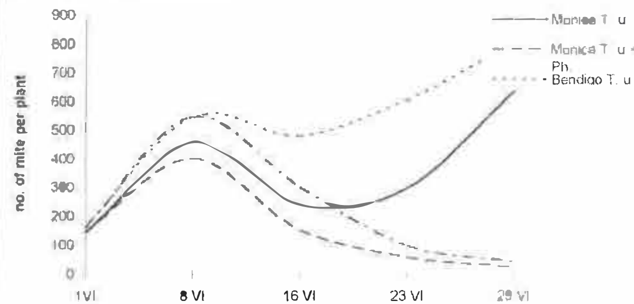

FIG 5. Effectiveness of Ph. persimilis in control T. urticae on sweet pepper

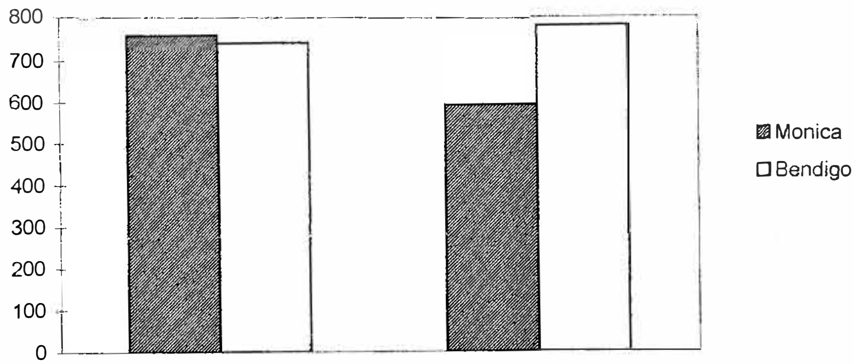

FIG 1 . Population density of T. urticae and T. cinnabarinus on sweet pepper, after five weeks of infestation

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Explaining the non-use of communication technologies from a 'negotiation' perspective

Cees Leeuwis
Department of Communication and Innovation Studies
WAU, Hollandseweg 1, 6706 KN Wageningen, The Netherlands

Introduction. Various authors have proposed to conceptualize computer-based decision aids as *communication technologies* (Winograd & Flores, 1986; Leeuwis, 1993), and to analyze the use or non-use of such technologies is communication theoretical terms. As an alternative to media-centred and receiver-centred explanations of communication technology use in communication science (see for an overview Leeuwis, 1993) I suggest to adopt an interaction-centred perspective. In this *interaction-centred* approach, communication processes are regarded as *processes of negotiation*. This implies, for example, that use of communication technologies must be understood in terms of interactions between the designers of the technology, those who use the technology for intervention purposes, intermediaries, end users etc. related to the social networks of these actors.

If communicative interventions which involve communication technologies imply a negotiation process, it needs to be clarified first what such a process involves. The exact nature of what is being negotiated varies from context to context. In general, it can be argued that both the *meaning of what is being communicated* and the *meaning of the communication process itself* are at stake. Developers of communication technologies usually incorporate a number of substantive or relational meanings. Such meanings are built in (often implicitly) in the form of various types of assumptions, for example:

* assumptions about human learning;
* assumptions about the user, such as:
    . assumptions about (future) information needs;
    . assumptions about foreknowledge and support needed;
    . assumptions about decision making and rationality;
* assumptions about natural and technical processes, opportunities and constraints;
* assumptions about socio-economic processes, opportunities and constraints;
* assumptions about advisory/educational processes;
* assumptions about communication patterns.

Assumptions that are incorporated in the technology may or may not adequately anticipate the context in which the communication technology is used. Users may wish to re-negotiate such underlying assumptions or may reject the technology altogether. Below, I will identify various reasons why the use communication technologies often remains limited, and indicate how these relate to various types of inadequate assumptions.

The fuzzy nature of information needs. For a long time communication technology development has been characterized by a considerable degree of 'technology push.' User needs have only played a subordinate role in communication technology development. In recent years, however, there is an increased interest in thorough user-oriented research. It appears far from easy, however, to identify relatively stable information needs of potential users. In social interaction, people continuously identify and solve certain problems, so that new problems and information needs replace previous ones. Hence, it is no surprise that users rapidly become 'bored' with certain communication technologies. Moreover, the wider context in which users operate is subject to continuous change. There is a danger that assumed information needs have become obsolete when they are eventually implemented in communication technologies.

In addition, there are methodological difficulties. It is difficult for anyone to analyze his or her own needs, and it is even more difficult to simultaneously evaluate the potential added value of an unknown technology in meeting such needs. Users are often not discursively aware of the needs that are already fulfilled, and have no need for information of which they are not even aware. In a way it can be argued that an information need only emerges when it is about to be fulfilled, i.e.

when particular information is within reach. Only when one has access to particular information does it becomes possible to evaluate whether or not there was a real need for the information.

Despite these inherent difficulties, many communication technologies incorporate rather specific assumptions about future information needs of users. In many cases, such assumptions are flawed, which severely limits the scope for using them.

Deduction, directiveness and normativity. Due to lack of insight in the information needs of potential users, designers and developers of communication technologies have often resorted to deducing such needs. Information needs have been deducted from available knowledge, formal rational decision-making models and legal regulations. In other words, developers of communication technologies have built technologies on the basis of their views on what the information needs of users *should be*. Thereby, they have positioned themselves as *experts* and adopted a rather directive and normative approach towards users. From the point of view of users, however, such a 'teacher-pupil' role division may be unacceptable and cause them to reject the technology. Here we see in fact how certain assumptions about information-needs, role division in educational processes, and the capacities and foreknowledge of users can be incorporated in communication technologies, and lead to limited use.

Decision-making versus learning. Many communication technologies are geared towards supporting decision-making with regard to specific decisions. In many such systems users are required to follow a linear decision-making process based on formally rational decision-making models. Deducing information needs in this manner is not without risk. Social-psychological studies (e.g. Janis & Mann, 1977) show that - when faced with problems - actors adhere to different patterns of decision-making, and that such patterns have a greater impact on actual information needs than formal decision-making models. Moreover, even if some patterns of problem-solving incorporate phases which are similar to those in formal decision-making models, these phases are run through in a non-sequential fashion (Engel, 1995), and can stretch over a longer time span. In everyday practice, it seems, decisions do not arise out of a discrete moment of decision-making, but rather from a long-lasting, often routine-like, and only partially conscious process of *learning*. Empirical research in agriculture has demonstrated that it is more effective, efficient and realistic to develop communication technologies which support learning than to develop communication technologies which support decision-making on specific issues.

Facilitating learning, then, poses different demands on communication technologies than supporting decision-making. Transparency and flexibility are important conditions in this respect. Both these conditions can be violated easily by the complex models which tend to underlie communication technologies. When aiming at supporting processes of learning it becomes more sensible to direct user-oriented research towards identifying knowledge and information-related *practices* (or patterns of behaviour) and *types of information needs*, than it is to search for specific information needs. In all, it seems plausible that communication technologies can incorporate models of decision-making and rationality which conflict with the rationalities and decision-making processes which are found in actual practice.

Diversity and inadequate segmentations into target groups. It is generally agreed that one of the most important conditions for successful communicative intervention is 'client orientation.' In order to anticipate diversity among potential clients or users, it is important to adequately segment users into target groups. It is always possible to make a variety of different segmentations for one and the same population (e.g. along lines of sex, age, strategy, economic position). Hence, it is important to identify the most relevant segmentations providing the sharpest possible insight into differences which relate crucially to realization of intervention goals. Frequently, existing characterizations (originally developed for other purposes) are taken as a starting point for communication technology development. In these cases there is a real risk that relevant points of diversity remain unidentified and that provisions to deal with this diversity are not incorporated in the technology. As a result users may find the technology too general and insufficiently tailored to their needs. Hence, in the process of technology development it is important to generate characterizations of diversity (i.e. 'models' of users) specific to the communication technology. Empirical research suggests that such characterizations may be fruitfully based upon observed differences in knowledge and information-related practices within the potential target population (Leeuwis, 1993).

The issue of diversity not only relates to assumptions about users, but may - indirectly - be connected with assumptions about natural, technical and socio-economic processes, opportunities and constraints. Different social groups may have rather different culturally and politically informed views, strategies and rationalities in relation to the natural, technical and socio-economic world. In any case, the assumptions regarding these matters incorporated into communication technologies are usually far from neutral. There may exist gaps or conflicts between the views, strategies and rationalities of developers as compared to end users of a communication technology.

Neglecting the external design. The design of adequate software and hardware often receives much attention in processes of communication technology development. Software and hardware components of communication technologies represent the technical dimension, or 'internal design". However, communication technologies have an social-organizational dimension as well: the contents of systems have to be updated regularly; technological infrastructures must be maintained; users require training and supervision; the parties involved must negotiate areas of responsibility, organize decision-making and solve conflicts. Communication technologies presume and induce organizational changes and develop within a social arena. This requires that various organizational arrangements are made; these arrangements can be labelled the 'external' design of the technology. A communication technology can only function optimally when sufficient attention is paid to both its internal *and* external design. Apart from initial supervision and guidance, the provision of a discussion partner can be an important aspect of the external design, which allows users to assess the relevance.of the information provided for the own situation. In relation to this, a striking phenomenon is that the most tangible function of many communication technologies seems to be that they provide an agenda for discussion. Frequently, the value attached to the opinions and views of the discussion partner tends to be higher than the value which is attached to the information and advice generated hy the communication technology. In this context, the efficiency of especially highly complex and costly communication technologies is at times debatable, since there are often alternative ways in which an adequate agenda for discussion can be generated.

Here we see that communication technologies incorporate inherently a number of assumptions which have social-organisational implications. This is most obvious in case of assumptions about the nature of advisory processes, and those about the user's foreknowledge and need for support.

Competition and lack of added value. Development of a communication technology is usually associated with the assumption that the particular technology will add something to an existing, or potential, communicative relationship. In must be recognized, however, that clients are usually part and parcel of highly sophisticated social networks in which information needs are created and solved. It happens regularly that communication technologies generate information which can already be accessed through other sources. The potential advantages of communication technologies do not result in such technologies having automatically sufficient added value to compete with existing knowledge and information infrastructures.

In this regard, it is important to recognize that communication technologies have a number of disadvantages. Communication technologies, for example, do not socialize easily, and their 'brains' are far less context-sensitive, flexible, creative and associative as compared to human beings. Moreover, users must generally make considerable material and immaterial investments before they are able to reap the benefits of communication technologies. In all, given the complexities and intricacies of human communication, communication technologies can easily be developed on the basis of misguided assumptions about existing communication patterns. In such cases, users tend to be disappointed with the return on the investment made.

Conclusion. There are several ways in which the developers of communication technologies may fail to anticipate the context(s) in which the technologies are to be used. Moreover, this problem can be traced back to various inadequate assumptions underlying the technologies. Such anticipatory 'misfits' are not as much the result of a naive ignorance on the side of the developers, but must be seen in the context of selections made in efforts to pursue specific interests and realize certain goals. The design of a particular communication technology, in other words, can often be best understood in the context of developers' strategic considerations. Examples of regularly observed strategic considerations by developers are:

* wish to tie customers;
* aspiration to create, maintain and reinforce an 'expert' versus 'layman' relationship;
* need to show the practical relevance of research models;
* ambition to alter organizational arrangements and missions;
* attempt to impose normative models of decision-making, rationality, reality and development;
* wish to demonstrate that one is not lagging behind in applying certain technologies;
* need to meet criteria for funding

At the same time, it is not possible to predict straight forwardly that built-in anticipatory 'misfits' result necessarily in a limited adoption - at least not if we define adoption in terms of actual possession of the communication technology in question. A 'perfect' communication technology which totally suits the variety of users for which it was intended does not exist, and users are quite able to - at least temporarily - cope with, and correct for its particular shortcomings. Anticipatory 'misfits' (e.g. lack of flexibility) frequently come to the fore only when users gain experience with a communication technology. Interaction-centred studies highlight that not only the development, but also the adoption of communication technologies is linked to social interests. Examples of strategic considerations for adoption are:

* conviction that - in the long run - one will not be able to survive without using the communication technologies;
* ambition to be identified as 'progressive;'
* effort to get access to special services or subsidies offered by suppliers of communication technology;
* free provision of communication technologies by suppliers in order to tie customers;
* attempt to maintain good relations with communicative interventionists;
* endeavour to secure access to particular actors or discourses;
* arrangements which effectively enforce use of the communication technology

More than the simple possession of or access to communication technologies, anticipatory 'misfits' are likely to affect the duration, quality and nature of the technology's use. With respect to the latter, communication technologies may well generate forms of use which were not foreseen. The question *to what extent* anticipatory 'misfits' will eventually prevent widespread adoption of a technology, however, can only be sensibly addressed in a contextual manner.

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REGULATORY ISSUES RELATED TO BIOLOGICAL CONTROL IN EUROPE

J.C. van Lenteren
Laboratory of Entomology, Wageningen Agricultural University
P.O. Box 8031, 6700 EH Wageningen, The Netherlands
email: joop.vanlenteren@medew.ento.wau.nl

ABSTRACT
Inundative and seasonal inoculative biological control as applied in greenhouses are based on regular introductions of natural enemies. These beneficial insects are mass-reared under unnatural conditions which may result in natural enemies of bad quality and failures of biological control programmes, so quality-control programmes are a necessity. Implementation of quality control tests may be augmented by the recent activities in the field of regulating importation of non-indigenous organisms which are taking place worldwide. The developments with regard to importation and legislation of natural enemies in Europe are discussed in this paper.

1. INTRODUCTION
Until recently, the use of beneficial arthropods was exempt for registration in most European countries, but several countries are implementing (very different rules for) registration now. For microbial pesticides quite strict registration procedures are followed in many European countries, often similar to those for chemical pesticides, but also here differences in procedures among countries exist. Uniform European legislation would prevent confusion and might help implementation of biocontrol, but such ruling is not expected to be developed in the near future. Importation and use of non-indigenous micro-organisms is covered by the registration procedure. For macro-organisms European countries have very different criteria to allow importation and releases, varying from no rules to rather strict criteria including the need to provide information on possible environmental impact. Rules for importation of natural enemies are on the agenda of several European countries. The FAO code of conduct (in preparation) might help standardization of ruling in the EU and worldwide, but needs significant adaptations will it be considered a positive development for commercial forms of biological control. Several of the quality control criteria could, in combination with other information, be used for registration procedures.

2. REGISTRATION OF BACTERIA, VIRUSES AND FUNGI (MICRO-ORGANISMS)
In general, products based on micro-organisms such as bacteria, viruses, fungi and protozoa need to be registered through similar procedures as those used for chemical pesticides in most European countries, as in the USA. The problem is, of course, that the registration procedure for chemicals contains many elements which are not relevant for micro-organisms. These expensive procedures do not encourage development of safer pesticides, which is at the same time advocated by authorities. Therefore, special criteria and guidelines for registration of microbials should be developed. In the Netherlands a specific application procedure has been designed for microbials, where the amount of preregistration data required depends on the risk category of the microbial, but European regulations largely overruled the procedure. Registration fees vary in Europe: some countries apply no costs for microbials (Denmark until 31 December 1995), apply a lower

fee for microbials (UK: c. 25% of the fee for chemical pesticides), or apply the same costs for microbials and chemical pesticides (The Netherlands since 1994). High costs for registration form a serious barrier for implementation of microbial agents.

The present situation in Germany is used to illustrate recent developments concerning registration as they are the most rigorous in Europe and the EEC Directive on legislation of pesticides (91/414/EEC) is similar to the German provisions (Klingauf, 1995). In the EEC and German registration procedures micro-organisms and viruses are included, but macro-organisms such as arthropods are not included. Micro-organisms are granted authorization if examination of the plant protection products shows that:

1. The plant protection product is sufficiently effective in the light of scientific knowledge and technique.
2. The precautions necessary for the protection of human and animal health in dealing with dangerous materials do not require otherwise.
3. The plant protection product, when used for its intended purpose, and in the correct manner, or as a result of such use:
   - does not have any harmful effects on human and animal health or on groundwater,
   - does not have any other effects, particularly with regard to the natural balance, which are not justifiable in the light to the present state of scientific knowledge.

It is clear that this description allows for different interpretations! "Any other effects" is defined as: all those effects which cannot be excluded with a probability next to security. Products will only be registered if other effects, especially those that affect the balance of nature, almost certainly can be ruled out. This particular point might create serious difficulties for registration of biocontrol agents! The EU registration procedures for micro-organisms and viruses are similar to those of Germany. The requirements are extensive and demand, among others, a thorough risk assessment including determination of effects on flora and fauna (for a list of requirements, see Klingauf, 1995). It is estimated that the **preparation of a dossier** complying with the EU guidelines would require 1.6 person year per active ingredient and will contain thousands of pages.

A positive point of the EC directive is the mutual recognition of registration. A member state must refrain from requesting new submission of test results and must recognize the registration of a plant protection product by another member state so far as the conditions are comparable.

3. REGISTRATION OF PREDATORS AND PARASITOIDS (MACRO-ORGANISMS)

Most European countries do not demand registration of macro-organisms such as mites, insects and nematodes. In Switzerland, Austria, and Hungary it is, however, necessary to register these kinds of natural enemies. Switzerland has no specific administrative procedure and registration is handled on a case by case basis. Austria applies regulations, and for Hungary official registration is required but not yet strictly enforced. France and Sweden are preparing legislation, and particularly procedures for Sweden look complicated. Other European countries are discussing the need of registration of macro-organisms. In the European Union macro-organisms are still exempt from evaluation under the new pesticide legislation (Directive 91/414/EEC). Although a uniform European legislation would prevent confusion and might help implementation of biocontrol, such ruling is not expected to be developed in the near future.

4. IMPORTATION OF NON-INDIGENOUS ORGANISMS

Use of non-indigenous micro-organisms is covered by the registration procedure, where more questions are asked about likely environmental impacts than for indigenous organisms. For macro-organisms European countries have very different criteria to allow importation and releases (from no criteria to rather strict criteria including information on possible environmental impact). In the UK, Germany and Denmark existing legislation applies to import of alien organisms. In the UK the release of non-indigenous organisms is prohibited under the Wildlife and Countryside Act, backed up by the Plant Health Order for pest species. Non-indigenous natural enemies have recently been included in the ruling, and an import license is needed for these organism through the Department of the Environment; the procedure for granting licenses is still under review. Also for Germany, procedures are under review. Officially, non-indigenous natural enemies cannot be introduced. Denmark enforced a new Act on the protection of the environment and releases of alien organisms (including biocontrol agents) are no longer permitted. Harmonization within the EU is under discussion, and there are efforts to include the FAO Code of Conduct for the Importation and Release of Biological Control Agents into the EU (Klingauf, 1995).

5. FAO CODE OF CONDUCT FOR IMPORTATION AND RELEASE OF NATURAL ENEMIES

FAO and IOBC are developing a code of conduct for import and release of biological control agents, with the aim" .. to set forth responsibilities and to establish voluntary standards of conduct for all public and private entities engaged in or affecting the distribution and use of biological control agents, particularly where national legislation to regulate their use does not exist or is inadequate".. Did the first versions of the code of conduct mainly deal with classical biological control, now also augmentative releases are included. The 1994 draft resulted in so many reactions that a final version has not yet been produced. The way in which the 1994 version was drafted could seriously complicate augmentative forms of biological control. The goal of this code is to harmonize regulation, to prevent unnecessary and complicated national legislation and to prevent undesirable, harmful effects of releases as much as possible. The new version, when formulated properly for different types of biological control, might form a basis for world wide harmonization of importations which is certainly beneficial for biocontrol.

6. CONSEQUENCES OF LEGISLATION FOR BIOLOGICAL CONTROL

Commercial biological control in Europe has a history of some 25 years (van Lenteren, 1995). The need to regulate biocontrol agents to conform with the use of other control compounds is felt only recently, both by ruling agencies and the biocontrol industries. For microbial agents registration is a must because of toxicological and environmental issues. The large diversity in registration requirements between countries makes it very difficult and expensive for the relatively small biocontrol companies to apply for registration. A unified procedure for Europe in the form of a EU Pest Control Agent Registration Directive would ensure that all member states will have the same requirements for registration, and also that once a biocontrol agent is registered in one country, registration in another country would be easier.

Registration of macrobials should be less demanding than that of microbials. A very general efficacy test to show that the natural enemy is capable of reducing target pest numbers, and -particularly with alien natural enemies - an estimate of environmental effects could suffice. A very important issue is here to develop a data base on geographical distribution, host range and possible influence on the ecosystem in which the agent will be used.

For commercial biocontrol no extra regulations would be needed. It is in the interest of the biocontrol industry to develop a certification system which includes quality control criteria to assure reliability to its customers. The framework in which testing can be effected (e.g. voluntary by producers, compulsory by governmental registration institutes, or as a form of certification under the responsibility of an official organization) is still under discussion. It is, however, clear that very strict registration procedures for macrobials are neither to the benefit of governments advocating pesticide poorer crop protection, nor to producers. This may be illustrated by the registration problems which were recently experienced in e.g. Japan and Morocco, two countries without any history of commercial biological control. These countries demand efficacy data for each natural enemy on every crop based on tests done by the authorities over several seasons. Test procedures appeared to be not very appropriate and lead to failures in determining efficacy and, thus in waste of time. In an IPM programme for vegetables, implementation can only start when all essential natural enemies are registered: this is expected to take a decade or more!

(The information in this section on regulation originates mainly from Ravensberg, 1994)

7. CONCLUSIONS

Quality control procedures for natural enemies are presently being developed for most of the commercially applied natural enemies in Europe. The quality control criteria relate to product control and are based on laboratory measurements which are often easy to carry out. The criteria need to be complemented with flight tests and field performance tests. Development and implementation of quality control procedures takes place in an IOBC/EU working group which is financially supported by the European Union.

Registration procedures for biological control agents are very diverse in Europe. For microbial agents, the costs of registration are often prohibitive for the natural enemy producers. Both, the high costs and the diversity in procedures hamper implementation of biological control. Standardization of registration in Europe will take about a decade. Similar problems exist for importation of natural enemies.

At the one hand many governments worldwide advocate pesticide poor or pesticide free production of food, at the other hand they simultaneously put up serious barriers for use of one of the most environmentally friendly and sustainable forms of pest control, biological control. If biocontrol scientists and producers are able to come up timely with good initiatives related to regulatory issues (registration, importation and quality control), reasonable compromises may be the result.

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QUALITY CONTROL TESTS FOR NATURAL ENEMIES USED IN GREENHOUSE BIOLOGICAL CONTROL

J.C. van Lenteren
Laboratory of Entomology, Wageningen Agricultural University
P.O. Box 8031, 6700 EH Wageningen, The Netherlands
email: joop.vanlenteren@medew.ento.wau.nl

ABSTRACT

Mass-rearing of natural enemies often takes place at small companies with little know-how and understanding of conditions influencing performance, which may result in natural enemies of bad quality and failures of biological control programmes. This makes robust quality-control programmes a necessity. Companies producing natural enemies and scientists working on quality control in Europe have agreed to cooperate intensively during the coming years to develop quality-control programmes. To date, only simple guidelines for laboratory tests have been developed, and much work still has to be done on designing relevant performance tests to show whether the present criteria do relate to field performance. A review of the state of affairs is presented.

1. INTRODUCTION

Although biological control of pests in Europe is known since around 1900, large-scale use of natural enemies of pests started only recently (van Lenteren, 1990). Commercial application of biological control spans a period of less than 30 years and started in 1968 with the use of a predatory mite to control spider mites (van Lenteren & Woets, 1988). In some areas of agriculture, such as apple orchards, corn, vineyards and greenhouses, it has been a very successful environmentally and economically sound alternative for chemical pest control (van Lenteren et al., 1992). National agricultural policies in Europe are presently strongly promoting non-chemical control strategies, including biological control. One reason for this is the decreasing number of active ingredients available for arthropod control. Of the 300 active ingredients currently on the market for insect and mite control, 120-180 are on the black-lists of several European countries.

Inundative and seasonal inoculative releases of natural enemies are commercially applied mainly in corn and greenhouse cultures in Europe and have increased considerably over the last two decades. Success of biological control in these crops is primarily dependent on the quality of the natural enemies which are produced by commercial mass rearing companies and sold to farmers. In 1968, when commercial biological control started in Europe, two small commercial producers were active. Today, Europe has about 30 natural enemy production companies. Only three have more than 100 people employed, the others are very small, often not having more than 10 persons contracted (Ravensberg, 1994). Total employment in Europe is circa 750 persons and growing. Only the three large companies produce the whole range of natural enemies (> 25 species) and bumblebees. Chemical companies also show some interest in biological control and one company has started to sell natural enemies. As biological control is a strongly developing market influenced by small competing companies, product quality and prices are continuously under pressure. This may in the short-term be profitable for growers, but in the long run it could lead to biological control failures. Were natural enemies properly evaluated some 20 years ago, nowadays some species of natural enemies are sold without tests under practical cropping situations showing that they are effective against the target pest. Total sales of natural enemies in Europe amounted to some 15 million US $ (end user value) in 1987 (with the largest producer having a market share of 65%) and to 60 million US$ in 1991 (market share of largest producer 50%, market share of three largest producers 85%). In addition to biological control, bumble bees used for pollination accounted for 10 million US$ in 1991. It is only at the larger companies that some control of quality of natural enemies takes place. The rise and fall of small companies and the poor quality of natural enemies they produce results in negative advertisement for biological control (van Lenteren, 1991).

The reliability and visibility of biological control would be improved considerably when standards for acceptable quality could be developed for all marketed natural enemies. Quality standards and efficacy data are also essential to obtain registration of natural enemies in several European countries, such as France, Switzerland and Austria.

The issue of quality control for natural enemies was discussed for years, but no concerted actions were taken until the end of the 1980s to develop standard procedures. The fifth's workshop of the IOBC global working group "Quality control of mass reared arthropods" (Bigler, 1991, Wageningen, the Netherlands) formed the starting point for a heated discussion among producers of natural enemies and scientists on how to approach quality control in the commercial setting of Europe at that time. Workshops funded by the IOBC and the European Union followed in 1992 (Horsholm, Denmark), 1993 (Nicoli et al, 1993, van Lenteren et al., 1993, Rimini, Italy) and 1994 (van Lenteren, 1994, Evora, Portugal), and as a result quality control guidelines were designed for about 20 species of natural enemies for practical testing in 1994/95. Also fact sheets about natural enemies and pests are being composed for training purposes. At this moment the guidelines comprise only characteristics which are relatively easy to determine in the laboratory (e.g. emergence, sex ratio, lifespan, fecundity, adult size, predation/parasitization rate). Work is now focussed at development of (1) flight tests and (2) a test relating these laboratory characteristics to field efficiency. Besides the IOBC global working group "Quality control of mass reared arthropods", two other working groups play an important role in developing quality control criteria: the IOBC/WPRS working group "Integrated Control in Glasshouses" and an EU funded working group "Designing and implementing quality control of beneficial insects: towards more reliable biological pest control".

2. QUALITY CONTROL GUIDELINES FOR NATURAL ENEMIES

The guidelines developed until now refer to **product control** procedures, not to production or process control. They were designed to be as uniform as possible so they can be used in a standardized manner by many producers, distributors, pest management advisory personnel and farmers. These tests should preferably be carried out by the producer **after all handling procedures just before shipment**. It is expected that the user (farmer or grower) only performs a few aspects of the quality test, e.g. percent emergence or number of live adults int the package. Some tests are to be carried out frequently by the producer, i.e. on a daily, weekly or batch-wise basis. Others will be done less frequently, i.e. on an annual or seasonal basis, or when rearing procedures are changed. For each test two coordinators were appointed to follow up the application of quality control tests by the producers and, upon their feedback, to reassess the technical and economic feasibility of those tests. If necessary, coordinators will contact relevant scientists or producers in order to design and carry out further studies which are essential for the completion of the quality control guidelines.

Most of the tests for the species listed below were accepted and will now function as

initial guidelines. This remarkable success is the effect of very positive cooperation between commercial producers and scientists active in the field of biological control of pests. In addition to the tests it was decided that fact sheets on natural enemies and pests were needed to inform new quality control personnel and plant protection services on biological details.
In the near future, flight tests and field performance tests will be added to these guidelines. Such tests are needed to show the relevance of the laboratory measurements. Laboratory tests are only adequate when a good correlation has been established between the laboratory measurements, flight tests and field performance.

Quality control guidelines have been developed for the natural enemies listed below:
- *Amblyseius cucumeris* (Oudemans) (Acarina: Phytoseiidae)
- *Amblyseius degenerans* Berlese (Acarina: Phytoseiidae) (provisional)
- *Aphelinus abdominalis* Dalman (Hymenoptera: Aphelinidae)
- *Aphidius* spp. (Hymenoptera: Braconidae)
- *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae)
- *Chrysoperla carnea* Steph. (Neuroptera: Chrysopidae)
- *Dacnusa sibirica* Telenga (Hymenoptera: Braconidae)
- *Dicyphus tamaninii* Wagner (Hemiptera: Miridae) (provisional)
- *Diglyphus isaea* (Walker) (Hymenoptera: Eulophidae)
- *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae)
- *Leptomastix dactylopii* Howard (Hymenoptera: Encyrtidae) (provisional)
- *Macrolophus caliginosus* Wagner (Hemiptera: Miridae) (provisional)
- *Orius* spp. (*O.laevigatus, O. insidiosus, O. majusculus, O. aldibipennis*) (Hemiptera: Anthocoridae)
- *Phytoseiulus persimilis* Athias-Henriot (Acarina: Phytoseidae)
- *Trichogramma brassicae* Bezd. (=T. maidis) (Hymenoptera: Trichogrammatidae)
- *Trichogramma cacoeciae* Marchal (Hymenoptera: Trichogrammatidae)
- *Trichogramma dendrolimi* Matsumura (Hymenoptera: Trichogrammatidae)

Full descriptions of the tests can be found in van Lenteren (1994).

Elements of all quality control tests are:

Quantity: predators: number of live predators in container
parasites: if delivered as adults: number of live parasites
if delivered as immatures: number of emerging adults over a certain period

Sex ratio: minimum percentage females; male biased ratio may indicate poor rearing conditions

Fecundity: number of offspring produced during a certain period;
for parasites it is also indication of the host kill rate

Longevity: minimum longevity in days

Predation: number of prey eaten during a certain period
(Fecundity, longevity and predation capacity tests can often be combined)

Adult size: hind tibia length, sometimes pupal size (often good indication for longevity, fecundity and predation capacity)

Flight: short-range flight (natural enemy can still fly)
long-range flight + predation / parasitization capacity (can fly and perform)

Field performance: capacity to locate and consume or parasitize prey / host in crop under field conditions

- Expiry date for shipment is given on packaging material
- All numbers / ratios / sizes etc. are mentioned on the container or packaging material
- Quality control is done under standardized test conditions: T, % RH, and light regime are specified for each test

In addition to the quality control guidelines, fact sheets have been developed for 5 pests (*Heliothis, Ostrinian, Sesamia, Tetranychus and Trialeurodes*) and 2 natural enemies (*Phytoseiulus and Encarsia*). Fact sheets for 15 other pests and 17 natural enemies are in preparation (for details, see van Lenteren, 1994). The fact sheets can be used when companies start the quality control tests. Most tests will be written out in detail in 1996. When needed special instructions will be developed for training personnel responsible for quality control.

4. CONCLUSIONS

Quality control procedures for natural enemies are presently being developed for most of the commercially applied natural enemies in Europe. The quality control criteria relate to product control and are based on laboratory measurements which are often easy to carry out. The criteria need to be complemented with flight tests and field performance tests. Development and implementation of quality control procedures takes place in an IOBC/EU working group which is financially supported by the European Union.

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QUALITY CONTROL OF *ENCARSIA FORMOSA*: FLIGHT TESTS

Joop C. van Lenteren, Connie J.A.M. Posthuma-Doodeman,
Michel Roskam & Gerben Wessels
Laboratory of Entomology, Wageningen Agricultural University
P.O. Box 8031, 6700 EH Wageningen, The Netherlands
email: joop.vanlenteren@medew.ento.wau.nl

ABSTRACT
Greenhouse biological control programmes are based on regular releases of natural enemies, which have been mass produced in "biofactories". Mass rearing often occurs under conditions different from those under which the natural enemies have to perform in the greenhouse. One of these differences is that, under mass rearing conditions, natural enemies hardly have to fly and search for hosts whereas in the greenhouse long distances have to be covered and the need to search for scarce hosts is no exception. These kind of differences necessitate quality-control testing. In such programmes not only numbers of natural enemies should be determined, but also the quality aspects of natural enemies related to their performance in the greenhouse. Simple quality control programmes for *Encarsia formosa*, parasitoid of whiteflies, and other natural enemies have already been designed. The next step is to include tests for flight and search capacity of natural enemies. Tests for short- and long-range flight capacity for *E. formosa* will be described.

1. INTRODUCTION
Biological control of greenhouse whitefly with the parasitoid *Encarsia formosa* is applied in several key greenhouse crops and demands mass rearing of millions of parasitoids on a weekly basis (van Lenteren, 1995). Quality control of mass-reared organisms is applied to check whether the quality of the laboratory population in biological control programmes is maintained. The overall quality of an organism is defined as the performance in its intended role after release into the greenhouse. The aim of releases of mass-produced natural enemies is to control a pest. ***The aim of quality control should then be to determine whether a natural enemy is still in a condition to properly control the pest.***

An initial quality control test for *E. formosa* was developed by the IOBC global working group "Quality control of mass reared arthropods". Besides this IOBC global working group, two other working groups play an important role in developing quality control criteria: the IOBC/WPRS working group "Integrated Control in Glasshouses" and an EU funded working group "Designing and implementing quality control of beneficial insects: towards more reliable biological pest control". The following items are measured: quantity and rate of emergence, sex-ratio, adult size, fecundity and flight activity (van Lenteren et al., 1993). This paper relates to one of the more difficult aspects of the quality test: how to determine the flight capability of natural enemies in a simple, reproducible and yet meaningful way?

Here we report on the design of a short- and long-range flight test, i.e. a test where *E. formosa* has to fly a distance of ca. 4 cm and ca. 50 cm to reach the trap, respectively. Distances of ca. 4 cm are similar to distances between leaves in a plant, and distances of 50 cm are maximum distances between plants in the greenhouse. We have experienced in the past that certain ways of producing or storing *E. formosa* led to seriously handicapped individuals which are unable to fly.

2. MATERIAL AND METHODS

2.1. Requirements for the short-range flight test

1. The test container should be developed in such a way that a daily check of emerged parasitoids is easy.
2. The test should be suited to determine at which environmental conditions *E. formosa* still flies (e.g. temperature, light and humidity).
3. The materials used should be reusable and standardized (or easy to standardize) in order to make the test as simple as possible to conduct by producers in different countries.
4. The animals caught on the trap should only be those that have flown. Animals should be prevented from reaching the trap by walking or jumping.
5. Minimal flight distance covered should be 4 cm.

The test unit consists of a glass cylinder, with a glass cover with sticky material at the top. A barrier of repellent material of 4 cm high is applied to the vertical wall of the cylinder, and prevents the wasps from walking to the sticky material on the glass cover plate at the top. Parasitoids are put (on leaves or on cards) on the bottom of the cylinder. The final set-up is given in figure 1. The history of development of the short-range flight test is described in detail in Doodeman et al. (1994) and Posthuma-Doodeman et al. (1996).

2.2. Requirements for the long-range flight test

1. The animals caught on the trap should only be those that have flown. Animals should be prevented from reaching the trap by walking or jumping.
2. Minimal flight distance should be 50 cm.

A one cubic meter flight cage with glass walls was constructed, in which a yellow sticky trap was hanging. Wasps were introduced as black pupae on cards on the bottom of the cage. The history of development of the long-range flight test is described in detail in Roskam et al. (1996).

3. RESULTS

3.1. Short-range flight test

It took quite a while before a set-up was developed which met the requirements as specified above.
The set-up to be proposed for the IOBC/EC quality control test will be the one as presented in figure 1, as it meets these criteria.

3.1.1. Influence of the condition of the pupae on the results of the short-range flight test

Cards with *Encarsia* pupae of two different ages were tested in the final set-up (figure 2). Of the *Encarsia's* that emerged from cards which were stored at 4°C for 16 days, 42 % was trapped. Two days of storage at 4°C resulted in 67 % of trapped *Encarsia's*.

3.1.2. Influence of temperature on the results of the short-range flight test

The flight test was conducted at three different temperatures: 15, 18 and 25°C. The cards used in this test were all from the same production date. Hardly any flight activity was found in the tests conducted at 15 and 18°C (trapped animals < 2 %). At 25°C the percentage of trapped animals was 77.6 which is within the range of tests with a good flight result (see figure 3).

3.2. Long-range flight test

Overall percentages parasitoids caught in the long-range flight tests were similar as in the short-range tests. At temperatures of 20°C and higher, and with fresh (non-stored) pupae, 70% or more of the introduced wasps were caught. But in comparison with the short-range test, first catches occurred a few days later, and the test, therefore, lasted a few days longer. A test with pupae that were stored for three weeks at 10°C resulted in a very low percentage caught (ca. 20%), which indicates once more that storage very negatively affects the flight capacity.

4. DISCUSSION AND CONCLUSIONS

4.1. Short-range flight test

A sequence of experiments and designs resulted in a set-up (figure 1) where (a) the wasps can reach the trap only after flight, (b) the whole set-up consists of standardized parts, is easy to assemble and reusable, and uses a small amount of space (15 x 15 cm) per glass cylinder in a climatized room, (c) counting of the trapped wasps can be done without manipulation of the cylinder and quick (only 2 minutes per cylinder), and (d) the effect of various environmental conditions and ways of storing the parasitoids can be evaluated. The short-range flight test can be used also for concurrent measurement of immature mortality, and parasitoid emergence pattern, elements which are included in the present quality control criteria.

4.2. Long-range flight test

The long-range test gave similar results as the short-range test. Performance of this test is, however, much more cumbersome than the short-range test: it demands much more time for counting, much more space and the test lasts a few days longer. We will make a comparison between results obtained with concurrent testing in both set-ups under the same conditions and then determine whether the long-range test is a valuable addition to the total quality test programme for *E. formosa*.

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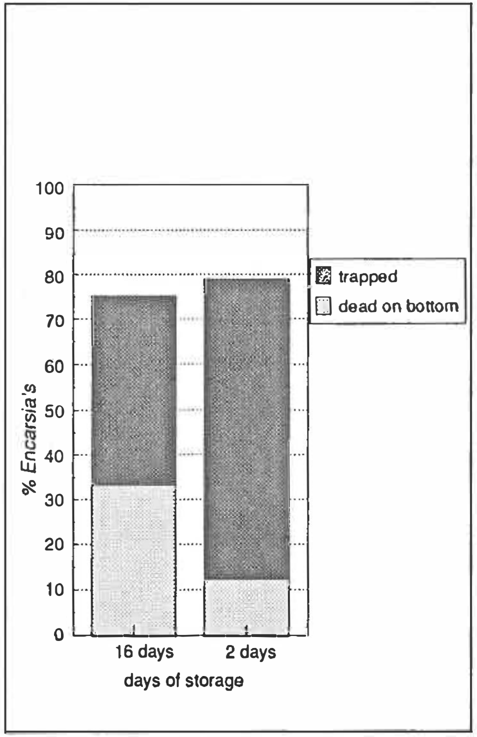

Figure 3. Influence of storage on % parasitoids trapped

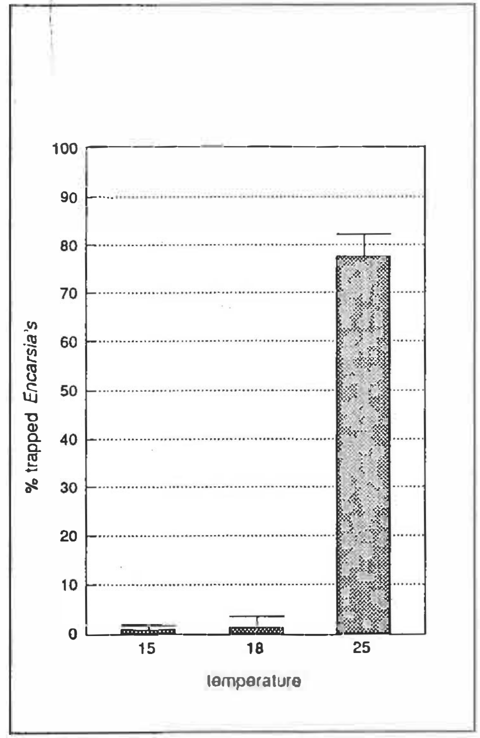

Figure 2. Influence of temperature on % parasitoids trapped

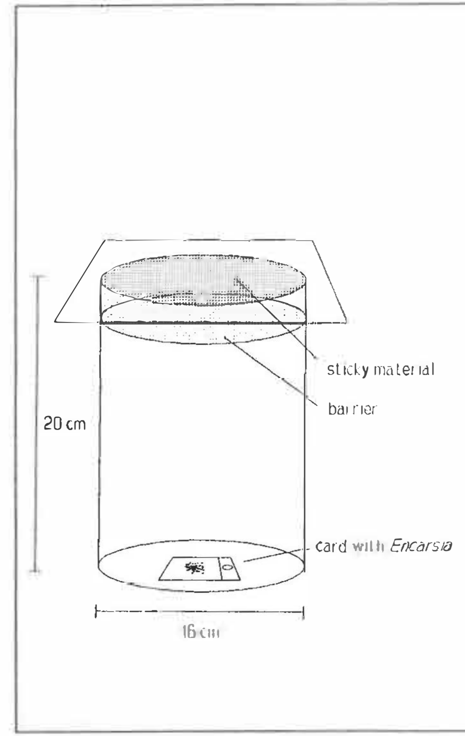

Figure 1. Set-up of the short-range flight test

CONTROL OF CATERPILLARS IN INTEGRATED PEST MANAGEMENT

Anton van der Linden
Research Station for Floriculture and Glasshouse Vegetables,
P.O. Box 8, 2670 AA Naaldwijk, The Netherlands

SUMMARY
A review is given on the species of Lepidoptera, which are noxious and increasingly cause problems in glasshouse crops in the Netherlands. The present possibilities of control within Integrated Pest Management programmes are limited because of resistance problems, incompatibility of chemical control with natural enemies against other pests, lack of adequate selective chemicals that have a legal approval in particular crops and because there are at present no effective natural enemies of caterpillars available. A further review is given on possible candidate natural enemies.

NOXIOUS MOTH SPECIES
So far, problems with caterpillars in glasshouse crops have not got much attention. In the first part of the 20[th] century ***Lacanobia oleracea*** (L.) on tomato was studied (Speyer & Parr, 1948). However, in Dutch glasshouses several caterpillars (Lepidoptera: Noctuidae) are noxious at present and have become a threat to IPM.

Chrysodeixis chalcites (Esp.) (Noctuidae: Plusiinae) occurs in the Netherlands as a pest since the late 1970's. Originally it is a (sub)tropical migratory species, which flies in from the south every year. The species is not able to overwinter in northern Europe, but in glasshouses it occurs all the year round nowadays. It is a polyphagous species. Among the crops attacked are tomato, sweet pepper, cucumber, lettuce, chrysanthemum and rose. The eggs are not laid in batches but singly and all around the crop. The caterpillar is a "false looper", which has three pairs of prolegs instead of the normal five. The mature larvae may also feed on fruit. The pupa is attached to a leaf or another substrate by means of a silken construction.

Spodoptera exigua (Hb.) (Noctuidae: Amphipyrinae) occurs in the Netherlands since the late 1970's. The natural distribution of this (sub)tropical species in Europe is mainly limited to the south, although it is also known to migrate to the north. The glasshouse population has its origin in Florida, from where it was introduced accidentally. This species occurs all the year round in glasshouses, but it is not able to overwinter outdoors in the temperate climate. For many years the host plant range was restricted to ornamentals, particularly chrysanthemum and gerbera. The pest has extended its host range to vegetables during the last years. *S. exigua* has spread to other glasshouse areas in the country in 1995. This species is notorious for its resistance against pesticides. The eggs are laid in batches, often in several layers and covered with a dense mass of hairs. The pupation takes place in the soil.

Autographa gamma (L.) (Noctuidae: Plusiinae) is a real migratory species. The moth is active during the day. In northern Europe it may have two generations per year. The females lay up to 500 eggs (Hussey et al., 1969). Damage is caused from June to autumn. There is much annual variation in the numbers caught during the migration observations, but the numbers may be very high. In horticultural crops this polyphagous species can cause much damage to chrysanthemum, sweet pepper, french beans and lettuce (Hussey et al., 1969; Jarrett, 1985) . So far, there are no indications that this species overwinters in glasshouses. Like *C. chalcites*, this species lays eggs singly and all around the crop. At 20°C, they hatch in six days. The caterpillar is a "false looper" and is very similar to that of *C. chalcites*. The pupa is attached to a leaf or another substrate by means of a silken construction, as with *C. chalcites*.

Lacanobia (Mamestra) oleracea (L.) (Noctuidae: Hadeninae) is a native moth in Europe. It is a polyphagous species. Some of the crops attacked are tomato, sweet pepper, lettuce, cabbages and occasionally cucumber. It may have two or at most three generations per year. About 1000 eggs are laid by each female in batches of between 60 and 300 eggs on the underside of leaves. At 20°C, they hatch in seven days (Jarrett, 1985). There are five to seven larval instars, which are completed in 33-39 days (Hussey et al., 1969). The larvae may feed on leaves, stems and fruit. Pupation takes place in the soil.

Mamestra brassicae (L.) (Noctuidae: Hadeninae) is a native species in Europe. It is a polyphagous species. Among the crops attacked are sweet pepper, tomato, lettuce, cabbages, and occasionally also carnation and chrysanthemum (Hussey et al., 1969). In many aspects it agrees with the former species.
Many other caterpillar species, including species from other families of Lepidoptera, could be added to this list.

PROBLEMS WITH CATERPILLAR CONTROL IN IPM

The application of biological control against pests in glasshouse crops does not allow the use of broad spectrum chemicals. However, other means also have shortcomings.
Applications of *Bacillus thuringiensis* formulations, which are compatible with biological control, are mainly effective against young caterpillars. These agents are not equally effective for all species of caterpillars. *B. thuringiensis* does not kill *S. exigua*. Moreover, in some crops it is difficult to reach the target. The agent is deposited on top of the leaves. Young caterpillars feed at the underside of the leaves, from which they only eat the surface. Once the caterpillars start to eat through the leaves they are less sensitive for the agent.

For the control of *S. exigua* a virus formulation is at present the most effective means, because chemical control is mostly a total failure. The limitation of this agent is that it is specific against *S. exigua* and it has so far only a legal approval in ornamentals in the Netherlands.

Teflubenzuron is not allowed in a number of glasshouse vegetables. This chemical is not very effective against *S. exigua*, and moreover it is harmful to *Orius* spp. and *Aphidoletes aphidimyza*. The application of diflubenzuron is restricted to ornamentals in the Netherlands.

Trichogramma spp., parasitoids of moth and butterfly eggs, are released in several glasshouse crops. The results are mostly very disappointing. *S. exigua* often lays the eggs in several layers covered with a dense mass of hairs, which hinders the parasitoid from oviposition. *C. chalcites* lays single eggs scattered around, which will cost the parasitoids much time to discover them. Moreover, the eggs stage of moths is only a few days in the glasshouse. Once the caterpillars have emerged, these parasitoids are unable to parasitize.
The use of pheromone trapping to control *C. chalcites* was studied in glasshouses, but the

efficiency was not high enough to recommend it as a control method (van Deventer & Minks, 1996). However, pheromones are being further investigated. It might be possible to prevent males from finding females by releasing extreme dosages of pheromones.
The use of light traps may be helpful, but cannot guarantee adequate control. Particularly high growing crops may give moths enough possibilities to escape. The ventilators should be closed when light traps are used to prevent moths from flying in from outside. Closing the ventilators may be a problem during summer.

CANDIDATE NATURAL ENEMIES

Surveys in glasshouses may yield interesting natural enemies, which are well adapted to this environment. In British glasshouses only a few species of predators and parasitoids have been found to attack *L. oleracea* (Speyer & Parr, 1948). The most common parasitoid found was *Pimpla instigator* F., which attacked the chrysalis. The seasonal emergence of this parasitoid did not appear to be well co-ordinated with that of its host. These authors also reported the very irregular appearance of *Comedo opaculus* Thoms., which is at present known as *Eulophus pennicornis* Nees (Hymenoptera: Eulophidae). They stated that this gregarious parasitoid had no appreciable control over its hosts, because the females deposit all their eggs upon one and the same host. In the Netherlands *E. pennicornis* also parasitizes *M. brassicae* and *S. exigua*, but its appearance is unpredictable. This parasitoid is not able to parasitize *C. chalcites*.

Cotesia plutellae Kurdjumov (Braconidae: Microgastrinae), which is a solitary parasitoid of *Plutella xylostella* L., has been found in association with young caterpillars of *C. chalcites* on sweet pepper and tomato (identification C. van Achterberg, National Museum of Natural History, Leiden). *C. plutellae* might be able to parasitize *A. gamma*, but it is doubtful that it parasitizes the other noxious caterpillars in glasshouse crops.
It might also be useful to pay attention to other parasitoid species, which are abundant on one or more of the moth species concerned but which do not occur spontaneously in glasshouses. In India *Litomastix* sp. (Hymenoptera: Encyrtidae) occurs spontaneously on *C. chalcites* (Rabindra & Jayaraj, 1987).

In Spain *Meteorus pulchricornis* (Wesmael) (Hymenoptera: Braconidae) and to a lesser extent *Hyposoter didymator* Thunberg (Hymenoptera: Ichneumonidae) occur on *S.exigua* (Caballero et al., 1990). In Mexico *Cotesia (Apanteles) marginiventris* (Hymenoptera: Braconidae) is the most abundant parasitoid on *S. exigua*, followed by *Meteorus laphygmae* (Hymenoptera: Braconidae) and *Pristomerus spinator* (Hymenoptera: Ichneumonidae) (Alvarado-Rodriguez, 1987).

A review of natural enemies of *Mamestra brassicae* in central Europe shows that the species with the highest constancy and abundance are *Microplitis mediator* (Hal.) (Hymenoptera: Braconidae), *Exetastes cinctipes* (Retz.) (Hymenoptera: Ichneumonidae), *Siphona flavifrons* Staeger and *Eurithia consobrina* (Meigen) (Diptera: Tachinidae). At least the latter species is also a natural enemy of *L. oleracea* (Turnock & Carl, 1995).

It would be most effective to use these natural enemies in a biological control programme which are able to control all the moth species in glasshouses. The caterpillar species within a subfamily may have some parasitoids in common. Parasitoids, which are effective against species belonging to different subfamilies of Lepidoptera are less obvious.

Predators are probably more polyphagous than most of the parasitoids. Therefore predators are the first natural enemies to try, without discarding the parasitoids in advance. One of the most promising predators seems the polyphagous bug *Podisus* *maculiventris* (Say) (Heteroptera: Pentatomidae). This predator occurs throughout North America. At 23°C the time of development from egg to the adult stage is 29 days (De Clercq & Degheele, 1992). The mean longevity is 64.7 days on a diet of *Galleria mellonella* (Lepidoptera: Pyralidae), and the total production of eggs is 710 / female (De Clercq & Degheele, 1993). The mean predation rate of the second to the fifth nymphal instar of *P. maculiventris* is increasing from 5.3 to 43.8 third instars of *S. exigua*; adult males and females kill 11.5 and 17.3 third instar caterpillars / day (De Clercq & Degheele, 1994). At the Research Station in Naaldwijk a rearing of *P. maculiventris* has been set up with insects kindly provided by the University of Gent, Belgium. Experiments are being designed to control caterpillars in sweet pepper and lettuce with the aim to further improve biological control and IPM programmes in glasshouse crops.

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PROSPECTS OF *CERANISUS AMERICENSIS* (GIRAULT) (HYMENOPTERA: EULOPHIDAE) AS A POTENTIAL BIOLOGICAL CONTROL AGENT OF THRIPS PESTS IN PROTECTED CROPS

Antoon J.M. Loomans & Joop C. van Lenteren
Laboratory of Entomology, Wageningen Agricultural University
P.O. Box 8031, 6700 EH Wageningen, The Netherlands
email: antoon.loomans@medew.ento.wau.nl

ABSTRACT
In May 1993 *Ceranisus americensis* (Girault) was collected in California and Arizona (USA) from alfalfa fields and flowering roadside vegetation. The evaluation of its effectiveness to supress thrips pest populations is reviewed. Pre-release experiments in the laboratory on the biology (development, life history) and behaviour (host species and size selection, searching efficiency) of the parasitoid and small scale experimental greenhouse release tests were executed. Based on the outcome, it is concluded that *C. americensis* does not show enough potential to control thrips under Dutch greenhouse conditions.

1. INTRODUCTION
The production of vegetables and ornamentals in greenhouses is increasingly characterized by the use of natural enemies to control insect pests biologically. During recent years thrips pests, especially the western flower thrips, *Frankliniella occidentalis*, have become the number one key pests in many greenhouse crops throughout Europe in addition to other thrips species (Tommasini & Maini, 1995), thus upsetting current IPM practices. Its introduction in Europe initiated a search for local and exotic natural enemies to control this new greenhouse pest. Alternative control methods have been developed in recent years using predators and are succesful in a number of crops (Riudavets, 1995). Studies to use thrips parasitoids, started in 1990 (Loomans & Van Lenteren, 1994). First, a collection and evaluation of *Ceranisus menes* (Walker) was made, originating from WFT populations from newly invaded areas in Europe and Brasil (Loomans, 1991) and from closely related thrips species, distributed worldwide, preferrably from areas with climatic condition similar to European greenhouses. Results of evaluation of this parasitoid are reported elesewhere (e.g. Loomans & Van Lenteren, 1994). Here, we report on the collection and evaluation of another eulophid paraoitoid, *Ceranisus americensis* (Girault). In order to evaluate its effectiveness, behavioural (host selection and searching efficiency) and biological (development, reproduction, life history parameters) characteristics were used as pre-release selection criteria in laboratory experiments and their dispersal and control capacity was studied by small scale releases in experimental greenhouse tests.

2. DISTRIBUTION AND COLLECTION
Until recently few data were available about *C. americensis*. Its distribution seems restricted to the Western part of North America (Triapitsyn & Headrick, 1995). It was first collected from alfalfa in Utah in 1912. In 1920 it was found on alfalfa in association with *F. occidentalis*, in Alberta-Canada (Seamans, 1923). Only recently it has been collected again from wild mustard, alfalfa, clover, etc. infested with a.o. *F. occidentalis* in various places in California and Arizona. Parasitoids collected from alfalfa infested with *F. occidentalis* in California and referred to as *Ceranisus* sp. by Greene & Parrella (1993), partly consisted of *C. menes* and *C. americensis* (Loomans, pers.id.).

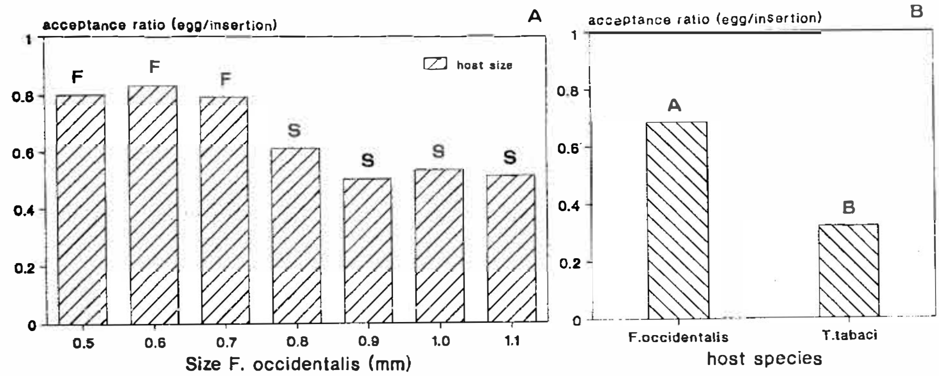

Figure 1. Average host acceptance ratios for *C. americensis* attacking *F. occidentalis* and or *T. tabaci*. A: host size acceptance ratio WFT (Loomans & Van Dijk, in prep.), B: host species acceptance ratio WFT and *T. tabaci* (Loomans & Pákozdi, 1996). Significances between sizes and species are indicated by different letters (K-W test for host size classes and M-W U test between species, p<0.05).

3. EVALUATION IN LABORATORY TRIALS

C. americensis females are 0.75 mm till 0.95 mm in length, the body black, scaly, proximal half of abdomen orange yellow and the distal half brown; antennae and legs (except coxae) pale, dusky (see Triapitsyn & Headrick, 1995). Until recently nothing was known about *C. americensis*, its biology has been subject of study only since 1993.

3.1. Host selection. Its attack and parasitization behaviour can easily be distinguished from that described for *C. menes* (Loomans, 1991): whereas *C. menes* quickly turns around after insertion of the ovipositor, lifting the larva in the air or tailing it behind her, *C. americensis* stays in the original insertion position, bending her ovipositor between her legs. In the laboratory the parasitoid attacked and developed successfully on larvae of *F. occidentalis*, *Frankliniella intonsa*, *Frankliniella schultzei* and *T. tabaci*. Insertion time takes 15-20 seconds on average, but when host-feeding occurs this can take minutes. Not in every host which is stung oviposition occurs, but first stage *F. occidentalis* larvae (up to 0.7 mm) are preferred as hosts (figure 1A). Attacks of second stage larvae are less successfull, only in 50-60 % of the inserted larvae an egg is found. When searching for hosts in an experimental arena, *C. americensis* encountered and attacked more larvae of *F. occidentalis* than of *T. tabaci* (25 vs. 10 during one hour respectively; Loomans & Pákozdi, 1996). When parasitizing two day old larvae, 68 % of the WFT larvae contained an egg, whereas in only 32% of the larvae an egg was laid when *T. tabaci* was offered.

3.2. Development. *C. americensis* is a solitary endoparasitoid of larvae. Like in other *Ceranisus* spp., parasitized larvae can move about freely and feed normally, and the development of prepupa and pupa is alike (Loomans & Van Lenteren, 1995): the prepupal central spot is orange red, the pupa is creamish white when newly hatched, becoming grey very quickly and black-brown before emergence. The life-cycle takes 27-29 days at 25 °C when developing on *F. occidentalis* and 25-26 days on *T. tabaci*, and is relatively long compared to that of their target pest. Like in *C. menes* developmental time is extremely long on both hosts at 20 °C and shows a large variation: 40-125 days (table 1).

Table 1. Biological parameters of *C. americensis* (Arizona) parasitizing *F. occidentalis*

t °C	strain	longevity	development time	r_m	R_o
20	Willcox	17.3 ± 5.1	71.9 ± 23.8	0.072	168.2
	Camp Verde	*	66.3 ± 15.8	*	*
25	Willcox	15.0 ± 1.2	27.9 ± 1.9	0.165	129.1
	Camp Verde	14.6 ± 1.8	28.1 ± 2.4	0.170	169.9

3.3. Life history parameters (table 1). *C. americensis* reproduces parthenogenetically, only females are produced. Immediately after a very short pre-oviposition period of a few hours only, *C. americensis* females start to lay eggs, up to 25-35 or more during the first few days. Compared to *C. menes*, the fecundity of *C. americensis* is much higher and its net reproduction (R_o) is not strongly influenced by temperature (cf. Loomans & Van Lenteren, 1994). *C. americensis* seems preovigenic (all eggs present at time of emergence), whereas *C. menes* is synovigenic (maturing eggs in the adult stage). The intrinsic rate of population increase (r_m) of *C. americensis* is much higher than that for *C. menes* at 25°C. At 20°C the r_m values for both parasitoids are low. Differences are largely due to the extreme long developmental period for both species at 20°C. Since both parasitoid species not only kill their host by parasitizing them but also by host-feeding, the overall death rate will likely be somewhat higher. At low host densities the full reproductive potential (table 1) will not be realized and the parasitoid's parasitization rate is of importance as well. The parasitization frequency changes strongly with ageing: they can lay 160-170 eggs on average, but this is concentrated in the first half of their life-time of about two weeks. The post-oviposition period is relatively long. Positive (high parasitization frequency) and negative (long developmental time) features of *C. americensis*, compared to their potential target hosts (Tommasini & Maini, 1995), seem to counterbalance its pre-release prospects, making its searching activity of great import importance.

4. EVALUATION IN GREENHOUSE TRIALS

In a small scale (100 m^2, about 700 plants) greenhouse experiment, 150-300 female *C. americensis* (Willcox strain) were released weekly in a rose crop, during the first. estimated generation time of thrips of six weeks (Loomans *et al.*, 1995).

Searching activity. First stage and early second stage larvae, which are the most suitable stage for the parasitoids, usually are more concealed than less suitable second stage larvae, which are more exposed. When released from a central spot, parasitoids reached the edges within one week an stayed in the crop up to two weeks. Numbers recovered were low (2-5%) and no wasps were found inside the trap plants and none of the thrips larvae in the trap plants were parasitized.

Control capacity. Releases resulted in establishment and maintenance of the parasitoid population at a very low level: less than 10 % parasitism occurred during a five month period. Parasitoids did not show any density response. The thrips population readily built up and the percentage of damaged roses increased: after 3 months 100 % of the roses were damaged, first on the sepals and later on the petals too, coinciding with an increase in the number of thrips (*F. occidentalis*, *T. tabaci*) present per flower. The release of about 2000 adult wasps did not result in any control of the thrips population.

5. CONCLUSION

Based on the parasitoid's long developmental time and low greenhouse performance we conclude that the *C. americensis* strain tested, does not show a large enough potential to control thrips pest outbreaks under Northwest European greenhouse conditions. The collection and selection of thrips parasitoids however, could not fully be exploited during the short period of time that was available during the course of the project and the existence of biotypes (geographical or host races) still needs to be properly evaluated, before a final conclusion can be drawn about the use of parasitoids as agents for the biological control of thrips pests.

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IPM FOR GREENHOUSE CROPS IN NEW ZEALAND: PROGRESS, PROBLEMS AND PROSPECTS

Nicholas A. Martin, Peter J. Workman and Terril Marais
New Zealand Institute for Crop & Food Research Ltd.
Mt. Albert Research Centre, Private Bag 92169, Auckland, New Zealand

ABSTRACT. Specialist advisors on IPM for greenhouse crops have been employed since 1991, but short term and uncertain funding has meant lack of continuity. The area of greenhouse tomatoes using IPM has declined from 50% to 30%. The newly appointed advisor is concentrating on crop change-over protocols, adult whitefly monitoring and research on tomato stemborer. Research on predators to control western flower thrips in capsicums and biological control of aphids is in progress. IPM programmes are available for roses and cymbidium orchids but there is no specialist advisor for ornamental plants. National pesticide resistance management strategies have been developed. The small size of the New Zealand industry and ambiguous government policies handicapped progress with IPM implementation.

INTRODUCTION. Successful adoption of integrated pest management (IPM) by greenhouse growers requires a willingness to use IPM, availability of the neccessary natural enemies, and other pest control products, access to advice and information, and suitable greenhouses. In New Zealand, we have made some progress towards meeting these requirements but have experienced some expected and unexpected problems. Progress, problems encountered, and future prospects are described in this paper.

INFORMATION/TECHNOLOGY TRANSFER. Most countries have a government extension service to assist growers adopt new technology such as IPM. However, during the 1980's New Zealand's national agricultural advisory service was reduced and is now privatised. A three year grant was obtained in 1991 for a national greenhouse IPM advisor. The appointment was followed by the registration of the pesticide, buprofezin and the availability of bumble bees to pollinate greenhouse crops. All of these developments stimulated the demand for IPM. The basic information on IPM for each crop was provided in manuals designed with the assistance of growers and published by Crop & Food Research (e.g. Martin 1993a,b, 1994a,b). Short term and uncertain funding for advisory positions resulted in a lack of continuity. After training and making growers aware of IPM, the first advisor left for a more permanent job. The position was temporarily filled by one of the research team, while further funding was sought. Advice to growers from retailers of natural enemies was often inadequate, while some growers were reluctant to pay NZ$35.00 for a manual or to ask for assistance even when it was provided free of charge!

The Government has recently funded schemes to assist the transfer of new technologies to industry (e.g. Technology for Business Growth). These schemes usually require a 50% contribution by the industry. In 1995, two year funding was obtained from a Technology for Business Growth (TBG) scheme for an advisor for IPM for greenhouse vegetables with support from the Fresh Tomato Sector of the Vegetable and Potato Growers' Federation (Vegfed) and Crop and Food Research. The scheme will use a small number of key growers attached to packhouses or marketing groups and the organisations will assist the dissemination of information to other members. Vegfed is now permitted to levy its members to fund research and development which means that it can contribute to schemes that require a 50% industry input and offer more certainty for the future of advisors. Crop & Food Research plan to provide more information to growers through leaflets on the biology of pests and natural enemies (e.g. Martin 1993c), while the Horticulture and Food Research Institute have established Hortnet, an Internet-based information system which Crop & Food Research may join.

GREENHOUSE TOMATOES. Tomatoes are the largest greenhouse vegetable crop in New Zealand (about 90 hectares). The mean area of crop per property is about 2000 m^2 usually consisting of two, low, single span roof greenhouses (Longly 1989). There is an increasing number of some modern multi-span greenhouses. The promotion of IPM coincided with the use of carbon dioxide, bumble bees, higher day/night temperatures and the new insecticide, buprofezin. In 1993, *Encarsia formosa* was used in over 50 hectares of crop. This has now declined to 30 hectares. Some growers are using *E. formosa* successfully, but others fail to control whitefly during winter and early spring. This failure is often associated with excess whitefly when *E. formosa* is introduced. Most crops are planted in late summer or autumn and the young plants are often infested with too many whitefly. Other crops are later infested from neighbouring properties. Parasitism by *E. formosa* was often less than expected during winter. When growers found that they could integrate the insecticide, methomyl, with use of bumble bees, they tended to rely on pesticides rather than biological control for whitefly. However, *Trialeurodes vaporariorum* resistance (1000-fold) to buprofezin has been found in Auckland and Marlborough regions (Workman & Martin 1995) which makes pesticide control of whitefly less robust.

The Fresh Tomato Sector of Vegfed supports IPM and employs the TBG advisor. An increasing proportion of fruit is distributed through packhouses or cooperative marketing groups which also support the adoption of IPM. Key problems to be tackled by the advisor in conjunction with selected growers include reducing new crop infestation with whitefly, monitoring adult whitefly populations and determining the conditions favouring *E. formosa* performance during winter. Each property will be inspected and crop change-over protocols will be negotiated with each grower. The most difficult problem will be facilitating cooperation between neighbours. However, there is more awareness and determination by growers to make IPM work.

Few growers know how many adult whitefly are in their greenhouses and most respond to high numbers too late. A simple monitoring process for greenhouse workers to use has been incorporated into the revised tomato manual (Martin 1995). It requires only a few minutes extra work per day and has already proved informative and stimulating for greenhouse workers. Recent Dutch research showed that *E. formosa* searches randomly for greenhouse whitefly juveniles, that day temperatures above 18°C are neccessary for parasite flight, and that searching efficiency is optimal at 25°C (Roermund 1995). During the short, winter days, the New Zealand greenhouse temperatures may not reach 20°C and rarely 25°C. It is hoped to model performance of *E. formosa* during the winter days and New Zealand greenhouse conditions to determine combination of day and night temperatures and numbers of *E. formosa* is needed to control whitefly. In old single-span greenhouses, which are uneconomic to heat to more desirable day and night temperatures, *E. formosa* introductions may be delayed until spring. However, *E. formosa* should work during winter in the modern large, tall, multi-span greenhouses.

Tomato stemborer, *Symmetrischema tangolias* (Lepidoptera: Gelichiidae), is an unpredictable pest of tomatoes which can kill plants when they are about 1.5 m high. Studies of its biology and susceptibility to pesticides are planned.

CAPSICUMS. The area of greenhouse capsicums increased recently while imports from

Australia were banned. There is no data on the current size of the industry. A pesticide-resistant strain of western flower thrips was discovered on a capsicum crop in 1992 (Martin & Workman 1994) and this strain has since spread to new areas of the North Island, often being found on capsicum crops or ornamentals. A non-diapausing strain of *Amblyseius cucumeris* selected from mites collected in Auckland is giving good control of western flower thrips (Workman *et al.* 1994), but in the winter it needs to be reintroduced into the crop at regular intervals, even when slow release bags are used. However, investment in facilities is required to expand the predator supply.

COMMERCIAL SUPPLY OF NATURAL ENEMIES. At present *Phytoseiulus persimilis*, *E. formosa* and *Heterorhabditis bacteriophora* are available for purchase by growers. New Zealand growers wishing to adopt IPM have few natural enemies available for purchase and pay a relatively high price. Restrictions on importing new organisms are a major factor limiting the choice of natural enemies. Organisms that may harm the indigenous fauna or flora are unlikely to be released. Host specific parasitoids are more likely to be imported than generalist predators. The price of natural enemies is high because the market is small. While it is theoretically possible for natural enemies to be imported in large quantities for distribution to growers, practical problems of transport and quality, especially freedom from contaminants, must be overcome. The small New Zealand market discourages investment in more products. More effective natural enemies are required for thrips control. Local Nabidae are unsuitable and little is known about indigenous Anthocoridae. However, a European species, *Orius vicinis*, was found on fruit trees in Central Otago (Lariviere & Wearing 1994), and we are trying to rear it so we can test its ability to control thrips on crops like greenhouse capsicums.

No natural enemy is commercially available for aphid control. The most promising predator initially was a brown lacewing, *Micromus tasmaniae* (Walker) (Neuroptera: Hemerobiidae). It is active all year, convenient to rear on the aphid, *Rhopalosiphum padi*, and eggs are easy to harvest. However, it has three disadvantages. Firstly, it lays its eggs on hairy surfaces, and capsicum, an aphid prone crop, is unsuitable. Secondly, the almost mature larvae require a refuge during the day. Thirdly, a high proportion of pupae can be parasitised. *M. tasmaniae* may have prospects for aphid control in low growing crops where it is introduced regularly as eggs. Aphid feeding Cecidomyiidae are present in New Zealand though *Aphidoletes* species have not been found. *Aphidius colmani*, which is in New Zealand, is the preferred aphid parasitoid for greenhouse crops.

The mealy bug ladybird, *Cryptolaemus montrouzieri*, is present in New Zealand as are the insect pathogenic nematodes, *H. bacteriophora* and *Steinernema feltiae* and the insect pathogenic fungus, *Verticillium lecanii*. All of these would be useful for IPM programmes, especially in ornamental crops.

CUT FLOWERS AND ORNAMENTAL CROPS. IPM for greenhouse roses works where western flower thrips is absent although the programme is not as robust as the successful programme for cymbidium orchids. Use of both programmes might increase if there were an advisor to assist growers. The lack of an advisor is partly due to the diversity of ornamental crops and a lack of a single organisation to coordinate the industry. Botanic Gardens are increasing their use of natural enemies and several plant nurseries use *P. persimilis*. *P. persimilis* is not recommended for two-spotted mite control on carnations because the predator adheres poorly to the leaves (Workman & Martin in prep). Changes in plant culture have increased concern about fungus gnats (Sciaridae) and shore flies (Ephydridae). At present the identity of the species causing the problems is unknown and no natural enemies are on the market.

Despite demonstrating that IPM can produce flowers that are pest and damage free, and can be exported to the demanding market of Japan, many growers still believe they can only achieve the desired standards by applying pesticides. Unfortunately, this has led to pests and diseases both developing resistance to pesticides.

PESTICIDE RESISTANCE. A National Pesticide Resistance Management Committee has organised the production of revised pesticide resistance management strategies which are about to be published. These highlight the use of natural enemies and IPM. Once they are published, the strategies need to be rewritten in "manuals" for each crop so that growers receive the information in a convenient form and can help conserve effective chemicals. This is important because fewer pesticides are being registered for minor crops such as greenhouse vegetables and ornamentals. Selective pesticides useful for IPM are also less likely to be registered. The long promised new legislation on Hazardous Substances and New Organisms, and Agricultural Chemicals could make pesticide registration (and importation of natural enemies) more difficult. In contrast, the government is promoting the concept of sustainable agriculture of which IPM is part, and IPM needs enhanced biological control but more selective pesticides but with less overall pesticide use.

CONCLUSIONS. The conflicting messages from the government on the future of New Zealand horticulture need to be resolved. The small size and diversity of the greenhouse industry will severely limit the resources available to develop and implement IPM. However, the investment in new greenhouses, support by Vegfed and increasing realisation by growers that they have no alternative all mean that there is a greater chance that IPM will be implemented much more widely in New Zealand.

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PATHOGENICITY OF ENTOMOPATHOGENIC FUNGI OF THE GENUS *ASCHERSONIA* AGAINST WHITEFLY

Ellis T.M. Meekes[1,2], Joanne J. Fransen[1] and Joop C. van Lenteren[2]
[1]: Research Station for Floriculture and Greenhouse Vegetables, Aalsmeer, and
[2]: Laboratory of Entomology, Agricultural University, Wageningen, The Netherlands

ABSTRACT

Isolates of entomopathogenic fungi belonging to the genus of *Aschersonia* from Asia and America were tested for pathogenicity on *Bemisia argentifolii* and *Trialeurodes vaporariorum*. Spores of 13 isolates were checked for germination on water agar. Considerable differences in germination percentages were found between isolates. In bioassays at 25°C using poinsettia plants, third instar larvae of either silverleaf whitefly or greenhouse whitefly were treated with spore suspensions of 10^7 spores/ml. Two weeks after spore treatment the larvae were examined for mortality by fungal infection and by other causes. Germination and infection levels were not correlated. Although there were considerable differences in pathogenicity of the isolates against whitefly, mortality caused by fungal infection was the same for both whitefly species. Isolates of Columbia, India and Thailand showed the best results with about 60% infection. Mortality by other causes of greenhouse whitefly (18%) was much higher than that of silverleaf whitefly (4%), thus causing overall mortality in the treatments to be 3 to 22% higher for *T. vaporariorum*.

1. INTRODUCTION

The greenhouse whitefly *Trialeurodes vaporariorum*, and since 1987 the silverleaf whitefly *Bemisia argentifolii* are important pests in greenhouse crops in the Netherlands. Biological control with the parasitoid *Encarsia formosa* has been carried out successfully in commercial crops. However, in some crops these parasitoids cannot suppress the pest population sufficiently; in ornamentals it is particularly difficult as a result of low damage thresholds. Considering natural enemies belonging to the category of micro-organisms, several entomopathogenic fungi are being investigated. Previous research indicated that *Aschersonia aleyrodis* can be a valuable asset to biological control because of its tolerance to lower humidities than other fungi and its compatibility with the parasitoid *Encarsia formosa* (Fransen, 1987; Fransen & Van Lenteren, 1994). Several other species of the genus *Aschersonia* have been reported on whitefly but little is known about their efficacy in controlling both *B. argentifolii* and *T. vaporariorum* in greenhouse crops. Here we report on the pathogenicity of several isolates of the genus *Aschersonia* which were collected from all over the world.

2. MATERIALS AND METHODS

Hosts: The same method was used to obtain third larval instars for both silverleaf whitefly and greenhouse whitefly. About 50 adults, both male and female, were put into clip cages on leaves of poinsettia (*Euphorbia pulcherrima* cv."Goldfinger") plants. The adults were given the opportunity to lay eggs for 24 hours, resulting in approximately 150 - 200 larvae per batch. The developmental period for *B. argentifolii* is about 14 days and for *T. vaporariorum* 19 days at 25°C before third instar larvae are present. When most of the larva reached the third instar stage they were sprayed. For *B. argentifolii* this meant that a mixture of second and third instar larva were sprayed as a result of overlapping larval cohorts.

Fungus: Over 40 isolates belonging to the genus *Aschersonia* were collected from all over the world, including isolates from existing collections as well as isolates from fresh material. Isolates were cultured on autoclaved millet in erlenmeyer flasks. The cultures were incubated at 25°C and L16:D8. The conidia were harvested after 3 weeks by rinsing cultures with sterile water containing 0.05% (v/v) Tween 80. The suspensions were diluted to 10^7spores/ml. The suspensions were checked for spore viability by spraying 2 ml suspension on water agar plates. After 24 hours incubation at 25°C percentage germination was determined by observing 200-300 spores per plate. Suspensions were sprayed on the underside of leaves using a Potter spray tower. After evaporation of the suspension plants were covered with a plastic bag for 24 hours to create a condition of 90-100% relative humidity (RH). Plants were kept under greenhouse conditions at 25°C. After removal of the bags, the RH was determined by greenhouse conditions: fluctuating between 40 and 80% dependent on season and photoperiod. The final examination for mortality and infection took place after two weeks when most of the healthy larvae had developed into adult whiteflies. Larvae were assessed for mortality caused by the fungus and mortality by other causes. A larva was considered infected if it turned opaque white or orange, depending on the isolate used; a larva was considered dead by other causes, if the insect was desiccated (= turned transparent brown).

3. RESULTS AND DISCUSSION

The origin of a selection of different *Aschersonia* isolates found in Asia and America we tested is given in table 1. *Ascheronia* species occur all over the world in subtropical and tropical ecosystems (Fransen, 1990) and have different whitefly species as host.

Table 1: Fungal characteristics of 14 isolates of the genus *Aschersonia* (fungal code, origin, original insect host, spore germination on water agar after 24 hours).

code		origin	insect host	germination (%)
A12	I92-784	Brazil	-*	70.8
A13	I92-787	Brazil	-	7.8
A28	-	Japan	*Paelius azalea*	96.8
A29	-	India	*Dialeupora*	21.6
A30	KV-129	Thailand	-	98.0
A31	KV-131	Thailand	-	95.6
A32	KV-132	Thailand	-	96.0
Aa1	ARSEF-430	Florida	Aleyrodidae	96.4
Aa4	ARSEF-992	Columbia	*Trialeurodes vaporariorum*	98.7
Aa6	KV-107	Columbia	*Trialeurodes vaporariorum*	98.6
Aa7	KV-108	Columbia	*Trialeurodes vaporariorum*	98.0
Ap1	-	India	*Dialeurodes cardomomi*	90.2
Ap2	CBS 917-79	SE-Asia	-	95.5

*: Insect host unknown, could not be identified by colonization of the insect by the fungus

Although most isolates show abundant germination on water agar, isolate 13 germinated at a very low level of 7.8%. Also on nutrient-rich medium the germination rate remained low. This isolate is capable of forming seçondary conidia(capilloconidia) which function is not yet clear (Evans, 1994). However, infection of whitefly was not observed in this bioassay. Isolate 29 showed the same tendency having low germination and low infection rates. On the other hand isolate 12 and 32 germinated for 70.8 and 98.7%, respectively, but the infection rates were very low regarding A12 which could not be reisolated from infected insects and only 9% and 12% of silverleaf whitefly and greenhouse whitefly, respectively, were infected by isolate 32 (figure 1). It is possible that some of these isolates have a more narrow host range. It has been reported that several species of the genus *Aschersonia* are restricted to whiteflies (Aleyrodidae) and other species to scale insects (Coccidae) (Petch, 1921; Evans & Hywel-Jones, 1990). Identification of the original host from which isolates were made, is often impossible, because of complete colonization by the fungus. These results suggest that only bioassays give insight in the pathogenicity and host range of the fungus.

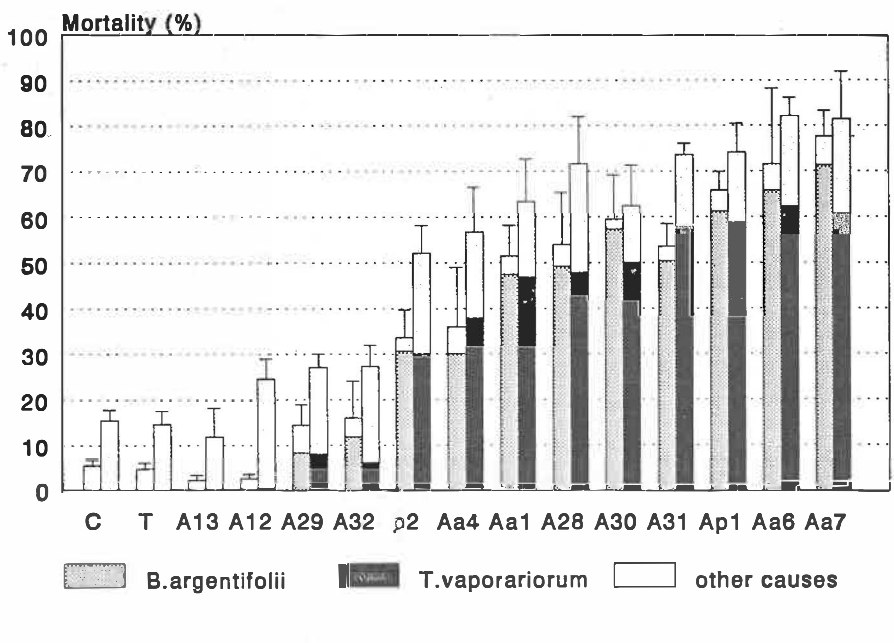

Figure 1. Mortality of larvae of *B. argentifolii* and *T. vaporariorum* by infection of isolates of the genus *Aschersonia* and other causes

The isolates A30, A31, Aa6, Aa7 and Ap1 caused 50% or more mortality by fungal infection. Although there was considerable variation between pathogenicity of the different isolates tested, the mortality caused by fungal infection between both whitefly species was not significantly different (figure 1). However the mortality by other causes for *T. vaporariorum* (18.8% +/- 5.1) exceeded the mortality of *B. argentifolii* (4.2% +/- 2.2). Poinsettia showing higher developmental rates for *B. argentifolii* than for *T. vaporariorum*, appears to be a more suitable host plant for the former whitefly species (Van Lenteren & Noldus, 1990). However, although one expects higher infection rates when a developmental period of the insect is extended and the host may be weakened related to higher mortality rates, the hypothesis that greenhouse whitefly with its longer developmental period at 25°C and higher natural mortality may be more susceptible to infection than silverleaf whitefly, is not proven by these results. Based on these pathogenicity results and spore production on semi-artificial culture media a selection of isolates was made for further research. Our research proceeds with experiments on dose - mortality relationships and survival of the spores on leaf surfaces. In the future attention will be given to direct and indirect influences of different host plants on infection and also greenhouse trials will be carried out to test the effectiveness in a practical situation with different ornamental crops.

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ADOPTION OF IPM BY THE GREENHOUSE FLORICULTURE INDUSTRY IN ONTARIO, CANADA

G.D. Murphy[1] and A.B. Broadbent[2]
[1]Ministry of Agric. Food & Rural Affairs, Box 8000, Vineland, Ontario, Canada L0R 2E0
[2]Agriculture and Agri-Food Canada, Box 6000, Vineland, Ontario, Canada, L0R 2E0

Abstract

An extensive survey of Ontario flower growers in 1994 showed that 28% were using Integrated Pest Management (IPM) based on our defining criteria. Biological control as a component of IPM has also been used widely, but less than 30% of programs gave satisfactory results. Most growers estimated that they now use less pesticides (mean of 29% less pesticide) than they did 5 years ago, but also noted that they now obtain better pest control, especially when using IPM.

Introduction

Greenhouse floriculture in Ontario is a major industry with a farm-gate value of $318 million in 1994. In 1988, the Ministry of Agriculture, Food and Rural Affairs together with Agriculture and Agri-Food Canada began developing and implementing IPM programs for the industry. Much of the background and developmental work was described in an earlier IOBC publication (Murphy and Broadbent, 1993).

When the program in Ontario began in 1988, the use of IPM was insignificant and monitoring tools such as sticky cards seldom used. Pesticides were used almost exclusively to control pest populations, usually based on a routine application schedule. Biological control was not used at all. Between 1988-94, a number of changes took place in the industry: IPM gained wider acceptance; use of sticky cards and other monitoring practices increased; and there was an escalating interest in and use of biological control. Despite this apparent progress however, there was no documented evidence of change in pest management practices. Estimates of the extent of IPM or biological control use were based on personal experience and opinion. There were 3 important reasons for determining the actual level of adoption of IPM:

1. To document the progress of the program between 1988-94.
2. To establish benchmarks for IPM against which future progress could be measured.
3. To identify weaknesses and areas for future improvement in the direction of the program.

This paper presents the results of a survey of pest management practices of greenhouse flower growers in Ontario, Canada.

The Survey

The survey was designed as a one-page questionnaire to be as simple as possible to maximize the response, while trying to obtain as much information as possible. The survey asked growers for information on 3 components of IPM: **monitoring, biological control** and **pesticide use**. It also asked for information on the size of the operation and the crops grown.

The questionnaire was sent (primarily by fax) to 151 growers, each of whom was telephoned beforehand to ask for their co-operation and to help ensure a rapid and high response rate. Survey returns were received from 133 growers, representing a total greenhouse area of 1,342,000 m^2 or 65% of the total flower production area in Ontario (Statistics Canada, 1994).

Results and Discussion

Results from each component of the survey are summarized and discussed below:

(i) Monitoring

Questions asked: Are you familiar with the term IPM?
Do you regularly monitor your greenhouse for pests?
If yes, do you use sticky cards and/or crop inspections?
Do you keep records of your monitoring results?

There was a high level of recognition by growers of the term IPM (90%), but it was more important in interpreting the survey results to be able to objectively identify users of IPM. The definition of IPM which we use in presenting the concept to growers in Ontario is: "IPM is a philosophy/strategy of pest control integrating all available tactics to reduce pest populations to an acceptable level in a cost-effective, environmentally rational manner". In Ontario, the use of a sound monitoring program (together with basic IPM practices such as good sanitation and weed control) is presented to growers as the first phase of an IPM program (Murphy and Broadbent, 1993), one which leads to the use of other control strategies such as biological control. We debated whether biological control should be a defining component of IPM, however ultimately it was considered that biocontrol was just one aspect of a broader pest management system; its use may be discontinuous over the course of a year or only relevant to certain crops or pests. Similarly, other components of IPM such as screening or chemical control may or may not be used depending on the situation.

Monitoring, should be regular and on-going, and independent of crops, pest complex or seasons. Without it, IPM cannot function to its potential, and if being carried out properly, monitoring is perhaps the best single indicator of whether IPM is being used. However, using crop monitoring as the key feature of IPM is not without problems either. For example, an overwhelming majority (96%) of respondents replied that they regularly monitor their crops. Yet it is unrealistic to suggest that 96% of Ontario growers use IPM! A question which allowed less room for individual interpretation was on record-keeping. Only 28% of growers replied that they systematically record their monitoring data. If growers are diligent enough to regularly monitor and take the time to record the information, it can be assumed that they will also be practising other aspects of crop protection which are components of IPM. Experience with commercial growers in Ontario since 1988, supports this assumption. **Record-keeping was the criterion we used to determine whether a grower was using IPM.** This definition, although convenient for the purposes of the survey, likely provides a conservative estimate of the impact of IPM, because there are many growers who may not keep monitoring records, but who have made considerable progress in understanding IPM and use of many of the concepts. (This is demonstrated by the survey results which showed that more than one third of growers who reported that they do not keep records of monitoring results, also reported using biological control).

The 28% of growers who, by our definition were using IPM, represented 44% of the growing area covered by the survey, and were on average more than twice the size of non-IPM operations (mean of 16,200 m^2 vs 7700 m^2). This discrepancy in size, demonstrates the lead role that larger operations are taking in adopting new technology and ideas. The influential nature of many of these companies in the industry is encouraging for the future expansion (in terms of numbers of growers) of the use of IPM, but it also suggests that future adoption of IPM (on an area basis) will be slower.

(ii) Biological control

Questions asked: Have you ever used biological control?
If yes, against which pests?
Were you satisfied with the results against each pest?
Will you use biological control again?
If you have not used biological control before, do you anticipate using it in the next 1 year/2 years/5 years/never?

A total of 39% of respondents (representing almost 50% of the area surveyed) had used biological control, primarily against fungus gnats, whitefly and thrips (Fig. 1). Of growers using IPM, 51% reported using biological control.

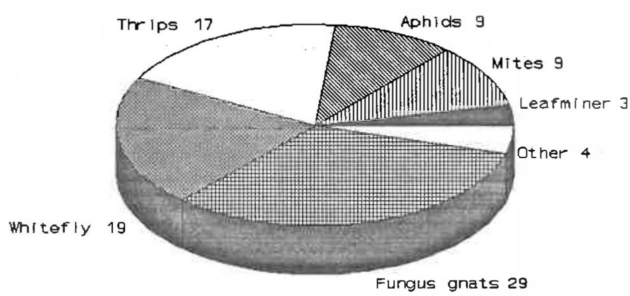

Figure 1. Number of reports of biological control being used against different arthropod pests in Ontario floriculture greenhouses in 1994 survey of 133 growers.

Fewer than 30% of biological control programs were reported as having satisfactory results and only 62% of growers indicated they would use it again. In contrast, for growers who had never used biological control, nearly 80% anticipated using it in the next 5 years.I is encouraging that so many growers have used biological control, but the low rate of success and the lack of confidence that growers who have used biological control have in it, is a concern. It will be difficult to build industry confidence in biological control when almost 80% of growers who have <u>not</u> previously used it, suggest they will in the future, but only 62% of grower who <u>have</u> used it, said they would do so again. This points to a pressing need in the future direction of our work in Ontario: to improve the success rate of biological control in commercial operations, to document successful programs, and to make use of the knowledge gained in these to promote its use to other growers.

(iii) Pesticide use

Questions asked: Over the last 5 years, have you changed your pesticide use patterns?
If yes, do you consider you now spray more/less/the same?
If more or less, can you estimate by how much (%)?
Compared to 5 years ago, do you feel your level of pest control is better/worse/same?
Do you keep pesticide spray records?

A key benefit of IPM is its potential to reduce pesticide use. How this is measured (e.g. Active Ingredient, number of sprays, cost) is a matter of debate, but it was not one that we pursued in this survey. Rather, a generic question was asked requesting growers to estimate in percentage terms, how much their pesticide use had changed over the last 5 years. Almost 90% of growers reported changing their pesticide use patterns, and of these, 70% claimed to be spraying less by an average estimate of 29%. Only 16% reported greater pesticide use, by an average estimate of 31%. There was a large difference in the mean size of operations which reported reduced pesticide use compared to those reporting increased use (11346 m^2 vs 6417 m^2 respectively).

Interestingly, there was no difference in estimated pesticide reduction between growers using IPM and those who were not. This is perhaps indicative of a general industry awareness of the need to reduce pesticide use, and the conservative nature of our definition of IPM, which would have excluded many growers who have nonetheless benefited from improved pest management programs in recent years.

When asked about their standard of pest control, 68% of growers using IPM felt they were achieving better control, and 8% thought it was worse. For growers not using IPM, 51% thought their pest control was better and 19%, worse. In total, spray records were maintained by 64% of growers, but where IPM was being used, this increased to 84%.

Conclusion

There are many positive developments in the implementation of IPM by flower growers in Ontario. A significant percentage reported using IPM, and at the time of writing (Dec. '95), it is estimated that more than 50% (by area) of the industry is now under IPM. At present, most IPM programs are carried out by the growers themselves with little input from consultants or scouts. This has limitations for the continued expansion of IPM since it is not practical for all growers to implement without assistance. Greater use of IPM consultants and professional scouts will be necessary for IPM to realize its full potential. It is also encouraging that larger (and more influential) operations are taking the initiative in the use of IPM and that so many growers have used biological control as a component of IPM. However, there are obvious concerns about the lack of success growers are having with biological control. If biocontrol is to be a practical option in the future, then it must be reliable, effective and consistent. This points to one of our biggest challenges as extension specialists and researchers serving the floriculture industry: to build confidence among growers that biological control is a viable component of a pest management program.

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IMPLEMENTATION OF IPM SCOUTING PROGRAMS FOR ORNAMENTAL CROP PRODUCTION

Julie Newman[a], Steve Tjosvold[b], Karen Robb[c] and Ann King[d]
University of California Cooperative Extension

[a]669 County Square Dr, Ste 100, Ventura, CA 93003-5401, USA
[b]1432 Freedom Blvd, Watsonville, CA 95076-2796, USA
[c]5555 Overland Ave, Bldg 4, San Diego, CA 92123-1219, USA
[d]625 Miramontes, Ste 200, Half Moon Bay, CA 94019, USA

Abstract
A statewide IPM demonstration project on ornamental crops was conducted in four major floriculture regions in California, USA. Scouts were responsible for pest monitoring, record-keeping, and weekly meetings with growers to make pest management decisions based on the information collected. Comparisons were made between the IPM treatments vs. the growers' conventional pest control practices. Results indicate that the scouted areas resulted in reduced pesticide usage without affecting plant quality. In several crops this was achieved at a lower overall cost, even with the increased labor for monitoring.

Introduction

Regular monitoring is the framework of good integrated pest management (IPM) programs and must be in place before biological control alternatives can be implemented. The backbone of a good IPM program is the scout who looks regularly for pests and plant abnormalities, records what is found, summarizes this information, and reports it to the grower for the final pest management decision (Ferrentino, et al., 1993). Since so many ornamental crop growers in the United States are still mismanaging pesticides because of the lack of sound monitoring practices, the primary objective of this project was to demonstrate the benefits and economic feasibility of using scouts in IPM programs.

Methodology

Scouts were hired and trained in four major ornamental plant producing areas in California: San Diego, Ventura/Santa Barbara, Santa Cruz/Monterey, and San Mateo Counties. Test crops examined in commercial nurseries included cut flowers, flowering and foliage plants, and outdoor container nursery stock. By implementing a scouting program with a variety of crops and site locations, we hoped to demonstrate that such a program could be effective on many ornamental crops grown in California and elsewhere in the United States.

Large crop areas were divided into smaller sections (pest management units) for ease of scouting and reporting. Monitoring methods included the use of plant samples, sticky traps and pheromone traps. The number of plants sampled depended on the size of the area, susceptibility of the crop to pests and diseases, crop value, and the amount of time involved in the monitoring. Sticky traps were used at a minimum rate of 1 per 1000 m^2 and a vertical strip equivalent to 20% of the surface area of the card was counted at each monitoring date (Heinz et al. 1992). Sampling strategies were developed during the initial months of the project to determine the minimum number of plants and traps necessary to obtain sufficient information concerning population trends at a reasonable cost.

The scouts met with the grower once a week to ascertain appropriate control measures. A clear communication system from pest management decision makers to the pesticide applicator was critical for the success of the program. Maps and/or flagging tape were used to designate infested areas requiring a pest control action.

Scouts were responsible for keeping detailed records for each operation. At the end of the project, these records showed how much labor was involved, amounts and choices of pesticides, and the quality of the crops produced. This information was used to prepare an economic analysis of the benefits of the IPM program as compared to the growers' conventional pest management strategies. Results of four cut flower crops are presented: roses, chrysanthemums, gypsophila and delphinium.

Greenhouse Cut Roses

Weekly monitoring began in the roses in May 1995 in a 0.4 ha. greenhouse in Santa Cruz County. Major pests and diseases monitored included western flower thrips (*Frankliniella occidentalis),* twospotted spider mites (*Tetranychus urticae*) and powdery mildew (*Sphaerotheca pannosa)*. Pest control decisions in the scouted area were made jointly by the grower and scout and were based strictly on monitoring data and rudimentary threshold levels that were developed during the project. Decisions regarding the use of fungicides to control powdery mildew were dependent upon whether fungal lesions were present, the location of lesions, and upon weather patterns conducive to the incidence of the disease. Spider mites were tolerated at low levels but densities between 3-8 mites per leaf were tolerated only if the weather forecasts predicted cool temperatures; mite populations above 8 mites per leaf were usually sprayed. The presence of thrips on sticky cards (blue and yellow) were not always indicative of thrips in the flower buds. When one thrips was found in a sampled bud, they were usually found extensively in that cultivar throughout the greenhouse, warranting an insecticide application.

The major benefit of the scouting program was early detection of pests and diseases at low levels. Additionally by specifically locating infestations, spot pesticide applications were made instead of the grower's routine practice of spraying all the greenhouses. Table 1 shows that scouting saved 35% of the applied pesticide volume as compared to the non-scouted area, and resulted in overall economic savings of 2.7 % ($192.50/ha.).

Greenhouse Cut Chrysanthemums

Scouting took place in a 0.8 ha. greenhouse in Santa Barbara County. Major pests and diseases included aphids (*Myzus persicae* and other aphid species), thrips (primarily *Frankliniella occidentalis),* leafminers (*Liriomyza trifolii*), twospotted spider mites (*Tetranychus urticae)* and tomato spotted wilt virus. The greenhouse was located near a mountain side with natural chaparral vegetation where western flower thrips populations migrate. As a result, thrips populations on sticky traps were high during warm weather, averaging as many as 700 per card per week. It was interesting, however, that the flowers were typically not infested, demonstrating the importance of not relying solely on sticky card traps when making pest management decisions (which is a standard practice in the industry). The scouting program from August to November, 1995 resulted in 44.4% fewer pesticide applications (Table 2) and an 18.4% savings ($89.44 per ha.) without affecting plant quality or salability. Cost savings occurred in August and September when insect activity was high, rather than in October and November when counts were lower.

Field Cut Gypsophila and Delphinium
The effect of the scouting program in field flowers depended upon the susceptibility of the crop to insect pressure and how intensively pesticides were used on that crop. In gypsophila, which is subject to a broad spectrum of pests (aphids, leafminers, thrips, twospotted spider mites, and botrytis), the scouting program resulted in 20.9% fewer pesticides used and an overall savings of 4.5% ($22.67 per ha.) without reduction in plant salability (Table 3). In delphinium, however, which is a relatively pest-resistant crop, only two applications of pesticides were made in the grower's standard program during the two month period of time the crop was monitored. The extra labor in the scouting program only saved one pesticide application and was considerably more expensive (Table 4).

Summary and Discussion
Further reductions in pesticide use could have been realized in the chrysanthemums and field flower crops if the growers involved relied more on the information gleaned from the scouting program to base their pest management decisions. Unnecessary pesticide applications were made in the scouted areas because of grower concern that insects would infest the crop in between the weekly scouting visits and cause significant economic damage. We deferred to the grower to make the ultimate pest control decision because we were dealing with crops that would be marketed. The project results, with even minimal pesticide reduction, however, should encourage these growers to rely more on the scouting reports.

The rose grower strictly followed monitoring data and threshold levels in making pest management decisions, significantly reducing pesticide use. A greater reflection of this should have been realized in cost savings but was not because inadvertently, more expensive chemicals were used in the scouted areas than in the non-scouted areas.

As a result of this project, growers/cooperators have developed a better sense of pest threshold levels and the correlation of sampling data with actual insect levels within the crop. The field flower grower/cooperator was so impressed with the benefits of the program, he hired one of the scouts full-time for his operation. The cut chrysanthemum grower is training one of his employees to continue the program.

Results of this project and the techniques used in scouting are currently being disseminated in statewide workshops. Based on the positive results, we are continuing the project and are working on refining threshold levels and incorporating biological control. Results on *Verbena* and *Hardenbergia* and preliminary results on roses have demonstrated that the scouting program facilitated successful biological control of pests. Future studies will demonstrate that the use of biological control in IPM scouting programs is economically feasible. These demonstrations should lead to increased adoption of scouting programs and the use of biological control in commercial ornamental production nurseries.

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Table 1.	Comparison of Scouting Program and Conventional Grower Program in Greenhouse Cut Roses 1/7 - 30/11/95 in ha.	
	Grower Control Greenhouses	Scouted Greenhouses
Scouting Tools*	_	$85.00
Scouting Labor**	_	$1,375.00
Pesticide Costs	$6,135.00	$4,932.50
Application Labor***	$1,050.00	$600.00
Total Pest Management Cost	$7,185.00	$6,992.50
Total Pesticide Spray Applied L.	46,715	30,363
*Cost of sticky cards; **$10.00/hr.; ***$6.00/hr.		

Table 2.	Comparison of Scouting Program and Conventional Grower Program in Greenhouse Cut Chrysanthemums 1/8 - 3/11/95.					
Grower Control Greenhouses in $/ha.				Scouted Greenhouses in $/ha.		
Month	Pesticides*	# Applied	Cost**	Pesticides*	# Applied	Cost***
Aug.	D, A	4	181.31	D	1	59.49
Sept.	A, L	4	232.30	A	3	221.78
Oct.	A	1	71.63	A	1	104.01
Nov.	_	0	0	_	0	10.52
Total		9	$485.24		5	$395.80
*D=Dursban, A=Avid, L=Lannate; **Labor & materials.Labor=$11.50/hr.;						
***Labor & materials. Labor=$12.00/hr.						

Table 3.	Comparison of Scouting Program and Conventional Grower Program in Field Cut Gypsophila 1/8 - 3/11/95.					
Grower Control Fields in $/ha.				Scouted Fields in $/ha.		
Month	Pesticides*	# Applied	Cost**	Pesticides*	# Applied	Cost***
Aug.	C, A, M, O	13	189.00	C, A, M, O	11	165.93
Sept.	P, O, D, A, M, C	12	104.01	D, P, A, M, O, C	7	117.77
Oct.	D, C, A, P, M, O	16	159.05	C, A, P, M, O, D	14	137.19
Nov.	C	2	50.18	C	2	58.68
Total		43	$502.24		34	$479.57
*C=Cutlass, A=Avid, M=Mavrik, O=Orthene, P=Pentac, D=Dursban						
**Labor & materials. Labor=$14.93/ha.				***Labor & materials. Labor=$12.00/hr.		

Table 4.	Comparison of Scouting Program and Conventional Grower Program in Field Cut Delphinium 1/8 - 30/9/95.					
Grower Control Fields in $/ha.				Scouted Fields in $/ha.		
Month	Pesticides*	# Applied	Cost**	Pesticides*	# Applied	Cost***
Aug.	_	0	0	_	0	30.76
Sept.	P, A	2	60.71	A	1	47.76
Total		2	$60.71		1	$78.52
*P=Pentac, A=Avid; **Labor & materials. Labor=$14.93/ha.				***Labor & materials. Labor=$12.00/hr.		

WESTERN FLOWER THRIPS: IDENTIFICATION, BIOLOGY AND RESEARCH ON THE DEVELOPMENT OF CONTROL STRATEGIES

Michael P. Parrella & Brook Murphy
Department of Entomology, University of California, Davis

ABSTRACT

The elements of an IPM program for *F. occidentalis* are being investigated at UC Davis: population level and decision making sampling plans for carnation, chrysanthemum, and rose utilizing plant samples and sticky traps; biological control using commercially available natural enemies and selected native natural enemies associated with field crops in California; biorational pesticides including the use of insect growth regulators and entompathogenic fungi; and (where tospovirus is a concern), a sampling scheme to assess the ability of invading thrips to vector tospoviruses.

INTRODUCTION

Thrips (especially the western flower thrips *Frankliniella occidentalis* [Pergande]) are arguably among the most serious pests of floricultural crops around the world. Direct feeding on opening flowers, feeding on pollen, defecation and oviposition in developing buds, and feeding on foliage with the concomitant transmission of tospoviruses causes serious damage to crops marketed for their aesthetic qualities. The spread of *F. occidentalis* and *Thrips palmi* Karny (melon thrips) has magnified the importance of quarantines as a regulatory control measure. This puts tremendous pressure on regulatory agencies because proper identification can be difficult and growers are placed in a position where 100% control is required. Obtaining complete control of thrips in a floricultural crop is an unrealistic goal.

For most growers, management of western flower thrips involves repeated applications of insecticides to the affected crops. Total reliance on this strategy is unwise given the propensity of this thrips to develop resistance and the increasing restrictions governing pesticide use. Screening greenhouses is not an option for most growers, biological control and host plant resistance have not evolved to the point where they can be incorporated into a thrips management program for a floricultural crop, and managing crop production cycles to mitigate thrips problems in a production range is often not possible given the market demand for product and limitations in space.

Taking these limitations into account, we have begun a research program aimed at developing sound thrips management strategies for floricultural producers. The full scope of the program in presented (Figure 1), but space limits providing information on all aspects of this program. Areas expanded include development of a sampling program, performance of natural enemies in cut flower crops, and efficacy data for some biorational materials (natural products and entompathogenic fungi).

Development of a Sampling plan. A 12,000 ft^2 greenhouse planted with standard chrysanthemums (6 cultivars) in late February through early March was followed from crop inception to harvest. Thirty sticky cards were uniformly positioned in the range and hung just above the crop. These were counted weekly for thrips. Thrips were counted from five terminals per bed per cultivar. Population development of thrips over time was compared using the traps and terminal counts. Data from chrysanthemum terminals revealed a low, but steadily increasing population of WFT. This was in contrast to the traps which showed relatively heavy populations of WFT which fluctuated through the cropping period. Relying solely on traps will result in erroneous control decisions by the grower. Future research will refine sampling techniques so that growers can better interpret the meaning of trap catches. We are concentrating on understanding the discrepancy between thrips caught on traps and those found on the crop.

Biological Control. In the greenhouse described above, releases of 12,000 *Amblyseius cucumeris* Oudemans (as sachets attached to plants and 500 *Orius tristicolor* (White) were released every other week on an alternate basis. Control cages (with and without natural enemies) were established over the cultivar 'Detroit News' to better assess the impact on the thrips population. Sampling was done as described above: any predators found in terminals were also recorded.

Regular releases of *A. cucumeris* and *O. tristicolor* did have an impact on WFT developing in chrysanthemums relative to the control cage. Although an impact on WFT was found, this was insufficient to provide a crop free of damage by WFT. Damage observed included physical injury to foliage and blooms as well as transmission of tospoviruses. In a commercial chrysanthemum where heavy thrips pressure is present, the regular, inundative releases of conventional natural enemies is not only uneconomical, but is insufficient to produce an acceptable crop.

PERFORMANCE OF BIORATIONAL MATERIALS

Many new insecticides falling under the category of 'natural products' are being developed by various sectors of the agrochemical industry. We are interested in evaluating these products for control of adult and larval stages of *F. occidentalis* taking into account possible repellency and the degree of residual performance. It is anticipated that such products will provide a superior degree of control with no hazards to the environment or worker health and safety. In addition, such products may provide compatibility with natural enemies.

A bioassay chamber was prepared using a ventilated carton fitted with a clear Plexiglas top; the carton contained a miniature blooming rose plant that was severed at the soil line. The stem of the plant protruded into a water filled vial which extended out the side of the carton. In this way an entire plant was included in the bioassay and the set-up maintained plant health for at least two weeks. Simulated field application rates were duplicated in the laboratory with a modified airbrush sprayer which delivered a known amount of material per unit area. Rates depended on the material sprayed and the protocols developed by the manufacturer. After the spray was dry, 30-50 adult or immature WFT were added to the carton. Generally 3-5 reps. were done at each dosage; controls were handled as regular treatments. Mortality was recorded for set periods after application and stopped when control mortality exceeded 20%.

A similar design was used for evaluating the performance of entomopathogenic fungi. However, the influence of relative humidity was measured by placing cartons in growth chambers with strict control over relative humidity. We report efficacy data for the product *Beauveria bassiana* (Mycotrol WP, Mycotech Inc., Butte, Montana). The performance of some biorational materials for control of WFT is very encouraging. Some new products gave 100% control of both adults and larvae upon contact. Residual control from these products has been observed for as long as seven days.

The fungus, *B. bassiana,* proved to be an effective control agent against both larvae and adults. Although it acted more slowly than some of the other biorational products, 100% control of WFT was obtained (Figure 2). The performance of the fungus was influenced by relative humidity, but this biological control appears less sensitive to abiotic factors than other species of fungi, such as *Verticillium lecanii.*

We have taken the next step for both these products which is to evaluate them for thrips control under commercial growing conditions and to determine their degree of compatibility with natural enemies. These studies are currently underway.

CONCLUSIONS

In California the development of practical IPM strategies for WFT as a pest of floriculture crops is still in its infancy. Quantitative sampling plans, taking into account within and between plant distribution of thrips have not been completed. In addition, minimal research has been done examining the relationship of thrips trapped on cards (the easiest method for growers to adopt) to what is actually present on the crop. This work is germane to the development of realistic economic thresholds. The incidence of transmission of tomato spotted wilt and impatiens necrotic spot virus is on the rise in the U.S., and methods must be developed to factor this into the development of meaningful economic thresholds. Assessment of the potential impact on the crop must take into consideration the ability of thrips to colonize the crop (if migration is the source) as well as the potential of virus transmission.

Biological control is currently not a realistic option for thrips control in commercial floriculture. A combination of natural enemies or a natural enemy together with a compatible biorational pesticide may provide the degree of control demanded in a cost effective manner. The search for other potential natural enemies (perhaps in field and greenhouse crops in the western U.S.) may uncover potentially effective natural enemies that could be developed for manipulative biological control in greenhouses.

Many new biorational pesticides are being developed for the greenhouse market. It is anticipated that such products will provide a superior degree of control with no hazards to the environment or worker health and safety. In addition, such products may provide compatibility with natural enemies. However, it is important that the labels for biorational materials reflect realistic use in the greenhouse. This is especially true with the entomopathogenic fungi. We anticipate investigating many of the critical areas outlined above in the coming year.

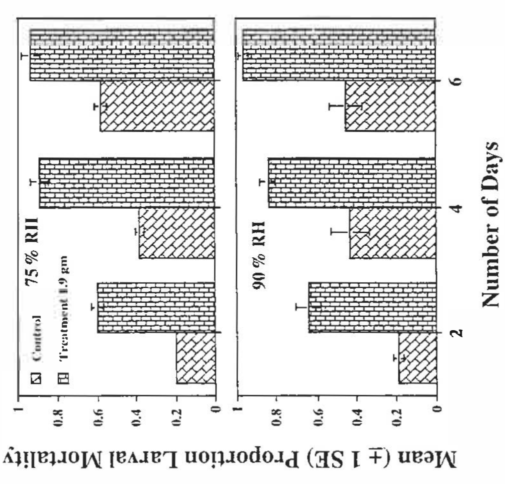

Figure 2. Performance of *Beauveria bassiana* against larval stages of the western flower thrips at two relative humidities

Thrips Attacking Floriculture Crops: Pest Management Considerations

Implementation of a Monitoring Program
- blue sticky cards
- leaf samples

Assess Threat to the Crop
- identification of thrips
- colonization of the crop
  - thrips on cards vs. plants
- source: internal/external
- sensitivity of the crop/cultivar to thrips injury
- sensivity of the crop to virus
- quarantine implications

Thrips Biology in the Greenhouse
- Pollen source/time of year
- Stage of crop development
- suitability of the crop as a host
  - adaptation period
- abiotic factors
- other crops nearby

Management Options
- Pesticide applications
- Biological control
- Cultural/Physical Options
  - screening; fallowing, etc.

Pesticide Applications
- conventional chemistry
  - tank mixes, sugar
- application methodology
- biorational materials
  - natural products
  - insect growth regulators
  - entompathogenic fungi
- postharvest clean up

Cultural/Physical Options
- feasibility of screening
- fallow period; crop scheduling
- less sensitive cultivars
- resistant lines

Biological Control
- Conventional Control Agents
  - *Amblyseius spp.*, *Orius spp.*
- Release strategies
- Alternative prey/food
- Novel control agents
  - nematodes
  - *Ceranisus spp.*

Figure 1.

USE OF NATURAL ENEMIES AS 'INDICATORS' FOR OBTAINING AN IPM LABEL

P.M.J. Ramakers
Research Station for Floriculture and Glasshouse Vegetables,
P.O.B. 8, 2670 AA Naaldwijk, the Netherlands

Abstract
In 1996 the marketing label MBT ('butterfly logo') is intended to evolve from an IPM label to an environmental label in a broad sense. Use of harmful pesticides will be restricted via a credit point system. Prescription of introduction rates for natural enemies ('sufficient effort' principle) will be replaced by inspection on the spot of a biological indicator ('sufficient result' principle).

Application of IPM methods can be stimulated via technical improvement of integrated control schemes, via political regulations and via the market mechanism. Creating an advantage for IPM via the market requires some kind of labeling to enable merchants and/or consumers to discriminate between IPM and conventional products. This is not a new idea: attempts of this nature were undertaken earlier in Switzerland (Migros Sano) and Sweden (Mäster Grön). In the Netherlands it became subject of serious discussions in the late eighties, when more biocontrol methods became available, but growers started to complain about the costs of multiple biocontrol. It was argued that even a small price advantage for IPM fruits would compensate for the extra costs, efforts and risks involved.

In 1990 a label called 'Controlled Production' was introduced by CBT (Central Bureau of Dutch Fruit and Vegetable Auctions). It was claimed a.o. that fruits marketed under this label were without detectable residues of pesticides (Nunnink, 1990). It was soon abandoned for various reasons, mainly because the attention of the public opinion was shifting from health related to environmental issues.

It was succeeded in 1992 by the MBT label (Gerritsen, 1991). MBT is an abbreviation for MilieuBewuste Teelt, in English: Environment Conscious Cultivation. The rules for earning this label focus on the production method rather than on the product, and are in a nutshell:

1. Chemical soil desinfection is forbidden.
2. The grower should start with IPM of a specified number of pests (for example 6 in sweet pepper and cucumber, 4 in tomato). During the season he may give up IPM of maximally 2 pests in pepper and cucumber and 1 in tomato.
3. Use of most insecticides is restricted (see Table 1).
4. Use of any insecticide (including the GREEN category of Table 1) is only permitted after sufficient effort to control the pest biologically.
5. Some environmentally undesirable fungicide applications are forbidden (Table 1).
6. Every fortnight a form with the complete and specified registration of (both chemical and biological) pest control has to be sent in to the auction.
7. MBT growers are submitted to residue checks by the auction, carried out at a much higher frequency than inspections by the Ministery.

CBT did not intend to create a 'third option' between conventional and organic farming. Rather the introduction of MBT was meant to transform the current practices into a more environment-friendly cultivation. Therefore the standards were set to make MBT practicable for all or at least the vast majority of the growers. Last year 2,300 glasshouse growers were participating. This year the label is available for tomato, sweet pepper, cucumber, melon, eggplant, courgette (possibly for strawberry, bean, radish, and lettuce) as well as for a number of outdoor vegetables and hard fruits. So far the market does not pay for the label, but some auctions give an artificial price advantage to their MBT growers.

Table 1. Pesticide classification in MBT. GREEN: without specific restrictions; PINK: restricted use; RED: around replanting or for local application only.

GREEN	PINK	RED	FORBIDDEN
ACARICIDES:			
clofentezine		abamectin	
fenbutatin oxide		cyhexatin	
hexythiazox			
INSECTICIDES:			
imidacloprid (Orbit)	buprofezin	deltamethrin	
pirimicarb (fum.)	imidacloprid (Admire)	methiocarb	
	oxamyl	methomyl	
	pirimicarb (gran.)	OP-compounds	
	teflubenzuron	piperonylbut./pyrethrins	
		propoxur	
		pyridaben	
FUNGICIDES:			
bitertanol	benzimidazoles	pyrazophos	chlorothalonil
fenarimol	bupirimate		maneb
imazalil	tolylfluanid		thiram
iprodione	triforine		
procymidone			
propamocarb			
triflumizole			
vinchlozolin			

In 1996 MBT will undergo a considerable reconstruction (Nunnink, 1995). The label will develop from an IPM label to a wider environmental label covering four categories: plant protection, energy efficiency, nutrient emission and waste disposal, with a relative importance of 40:30:20:10. The meanwhile very complicated set of regulations about pesticide use will be replaced by a simple penalty system. For each chemical application the grower will lose some credit points, depending on the treated area and the harmfulness of the pesticide. Environmental criteria for defining 'harmfulness' are under way (Reus, 1991). For the time being the classification as in Table 1 will be used: a grower will lose 1 point for applying a 'green' chemical, 3 for 'pink' and 5 for 'red' out of a total 'credit' of 40. The credit balance over 4 previous quarters will be decisive. The minimum credit for staying in MBT (per category and/or for the total) is still to be defined.

Biocontrol will continue to be compulsory for those crops to which it is applicable. However, MBT will no longer require the introduction of specified numbers of natural enemies. This part of MBT (so actually the definition of 'sufficient effort' in rule nr. 4) was increasingly criticized, because it did not allow growers to save on the increasing costs of biocontrol, for example by investing more time in monitoring, redistribution of natural enemies, applying good hygienic standards, maintaining open rearing systems, stimulating natural control, etc. Being asked for another criterion for 'proper biocontrol', we have proposed to use the presence (and abundance) of one of the natural enemies of a key pest for this purpose, after the example of indicator species used in nature protection. It was supposed that such an approach would give more freedom to the grower, would offer an objective parameter to the auctions (cheaper than checking on residues!) and would appeal more to environmental organisations since it rewards the result rather than the subjective effort.

Table 2. Biological indicators in future MBT.
or: at the option of the grower; B: accepted only if A does not occur.

CROP	KEY PEST	INDICATOR
tomato	A. whitefly	*Encarsia formosa* or *Macrolophus caliginosus*
	B. leafminers	all larval parasitoids
sweet pepper	A. thrips	*Amblyseius* spp. or *Orius* spp.
	B. aphids	parasitoids or predators
cucumber, melon	whitefly or	*Encarsia formosa*
	thrips	*Amblyseius* spp. or *Orius* spp.
eggplant	whitefly	*Encarsia formosa* or *Macrolophus caliginosus*
	or thrips	*Amblyseius* spp. or *Orius* spp.

First a number of criteria for choosing the biological indicator were defined:

a. The key pest should be one that can be controlled biologically with a fair chance of success.
b. Biocontrol of this pest should be difficult without controlling other pests

selectively; in other words: the indicator should preferably be susceptible to broad spectrum pesticides.

c. It should not matter whether the indicator's population originates from an artificial introduction.
d. The indicator should be present and detectable during the major part of the season.
e. The quantitative requirement should be so high, that such a population density can not be realized instantaneously with a forced introduction, *)
f. but so low, that the inevitable seasonal fluctuations are taken into account. *)
g. The judgment may require a considerable expertise from the MBT inspectors, but should not be time consuming.

*) These MBT standards should thus neither be confused with recommended introduction rates nor with control effective densities (*cf.* Ramakers & van der Maas, these proceedings).

The biological indicators suggested per crop are listed in Table 2 and the quantitative requirements in Table 3. This proposal is accepted as a principle, though it might undergo some minor alterations before becoming operational. It is also adopted by the Center for Agriculture and Environment in the process of preparing a future environmental label with stricter standards than MBT (Bouwman, 1995).

Table 3. Abundance of biological indicators required in MBT.

INDICATOR	REQUIREMENT
Encarsia formosa	50% black scales on leaves where white scales start hatching
Macrolophus caliginosus	plant incidence 100%
leafminer parasitoids	larval mortality by parasitization + host feeding 15% in February increasing to 40% in May
Amblyseius spp.	leaf incidence 75% on mature top leaves
Orius spp.	50 nymphs + adults in 100 fully open flowers to be established by immersing flowers in alcohol
aphid parasitoids	5% mummies ignoring hatched mummies
aphid predators	plant incidence of larvae 100% in aphid colonies

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DECISION SUPPORT SYSTEM 'CAPPA' FOR IPM IN SWEET PEPPER

P.M.J. Ramakers & A.A. van der Maas
Research Station for Floriculture and Glasshouse Vegetables,
P.O.B. 8, 2670 AA Naaldwijk, the Netherlands

Abstract
Decision making in crop protection was analyzed, and a prototype for an automated decision support system was developed using expert knowledge of research entomologists and IPM advisors. Sweet pepper was chosen as a pilot crop, with emphasis on Western Flower Thrips and its predators. After being tested and commented on by 11 growers in 1993, the final version called CAPPA was offered to commercial companies for further development including translation to other crops.

During the eighties an increasing number of beneficials became commercially available (Ramakers, 1992). Recently a supplier proudly reported that he had managed to sell 22 different natural enemies to an individual eggplant grower in one season! Some of these beneficials were launched after little if any experimenting. Likewise, claims about improved genetic quality of 'new strains' of natural enemies are sometimes not supported by any (documented) research. Added to the fact that an increasing number of companies and individuals operate on the market of IPM consultancy, it is understandable that sometimes a grower does not see the wood for the trees anymore.

Developing an IPM program that a grower could run on his own computer was thought to be one of the possibilities to bring back some order in this chaos. Sweet pepper was chosen as a pilot crop because it is one of the three major IPM crops in the Netherlands, and because IPM on this crop is more complicated than on tomato and more predictable than on cucumber. First the process of decision making was analyzed, starting from the signalisation ***casu quo*** anticipation of a pest problem until the final decision of the manager whether and how to interfere (van der Maas, 1991 and 1992). This framework was 'filled' with knowledge provided by an expert group of researchers and advisors, and a prototype of the program called 'CAPPA' was tested by 11 experienced IPM growers in different parts of the country in 1993. Their comments were discussed again with the experts and included in the program (Ammerlaan & van der Maas, 1993).

CAPPA does not produce long term prognoses, as decision making for plant protection in glasshouses is known to proceed on a week-to-week, sometimes day-to-day basis. It is based on population dynamic experiments carried out over many years in experimental and commercial glasshouses, from which threshold values rather than rates of increase are used. The input is the classification of the population densities of a pest and its natural enemies. Each combination of densities leads to a specific recommendation, together with a motivation to let the grower know where this recommendation was based on. Recommendations to be expected include "consider introduction of beneficial X", "continue without interfering", "try to increase air humidity", "interfere with chemical Y", "increase monitoring frequency to weekly", *etc.* The internal decision rules of the program are described in an internal report of our institute (Ammerlaan & van der Maas, 1992). CAPPA can deal with only one pest at a time. The program requires a recent input, not older than 2 weeks. Only in doubtful situations it may look at the previous record to see whether the situation is improving or deteriorating.

Educating growers to adopt frequent monitoring as a common practice was one of the secondary objectives of this project. However, for each counting method suggested, the experts group has carefully questioned whether or not the addition to the program would really serve an operational purpose. So in the original CAPPA anything that was considered scientific or cosmetic ballast was left out to increase the probability that the growers would fulfil the remaining requirements.

For the designers of CAPPA control of **Western Flower Thrips** was the most challenging part, since it is a central problem in IPM and there is no easy solution like a selective chemical that would make any expert, human or electronic, superfluous. The thrips and its main natural enemies, anthocorid and phytoseiid predators, should be classified as indicated in Table 1 on the basis of relatively simple counting methods (recommended sample size 25 flowers and 50 leaves per object). Additionally, the program might ask whether or not symptoms of Tomato Spotted Wilt Virus have been observed. In exceptional cases (very good phytoseiid population, but still too many thrips and not enough anthocorids) the program might suggest to establish the larvae:adult ratio of thrips. Since (fruit) damage is caused by the larvae, a very low ratio justifies postponement of chemical interfering.

Table 1. Classification of Western Flower Thrips and its predators in CAPPA

THRIPS		ORIUS		AMBLYSEIUS	
adults/flower	qualification	# / flower	qualification	incidence (% leaves)	qualification
0	no	0	no	0	no
< 1	low	< 0.1	too few	< 30	low
1-3	moderate	0.1-0.5	promising	30-75	reasonable
3-10	alarming	0.5-1.0	good	> 75	good
10-30	high	> 1	very good	[> 2/leaf]	very good
> 30	extreme				

Establishing the average density of **aphids** was considered senseless because of the extremely clustered initial distribution of this pest. Most aphid species first colonize senescent leaves (absent in young crops), then shoot tops and finally mature leaves. Presence of aphids in the tops is considered alarming, and rather than to count aphids it is recommended to tag such hot spots, provide them with high rates of natural enemies and check regularly. It is disputable how long a grower should continue to introduce aphid parasitoids. Based on our own research we suggested to consider 10% mummies on the plants sufficient, because in experiments with *Myzus persicae / Aphidius matricariae* we found repeatedly that aphid population collapse soon after such a record. This figure seems low, and is indeed often criticized for being so even by experienced IPM advisors. The 'mummy rate', however, should not be taken for a parasitization rate (like the rate of black scales in whiteflies, which really represents the rate of parasitization in a particular age class). Besides it was concluded from the same experiments that most parasitized aphids leave the plant before mummification (Ramakers, 1989).

Peppers can be affected by a number of aphid species, having partly different parasitoids. Also the susceptibility to insectides differs. If the grower can recognize the aphid species, the program will advise accordingly. For chemical correction pirimicarb and (not available when CAPPA was built:) imidacloprid are suitable insecticides. However, they should be applied in a modest way, since they are moderately harmful to, respectively, phytoseiids and anthocorids. So after a full rate application of these aphicides it is wise to restart monitoring the thrips/predators complex, even if thrips was considered under control before.

Like aphids, **spider mites** have a very clustered distribution, so again tagging and mapping is more appropriate than counting individuals. For the interaction between this pest and the predatory mite *Phytoseiulus persimilis*, a simulation model existed. Although validated on cucumber (Sabelis *et al.*, 1983), it would be not too difficult to adapt it to pepper. It was, however, not used in CAPPA for two reasons. Firstly, the input required even by a simplified version of the model (Sabelis, 1983), *i.e.* estimating the percentage of leaf surface being damaged in each hot spot, was considered too time-consuming. Secondly, the output of the model, *i.e.* the introduction rate of predators required for preventing economic damage without using acaricides, is usually higher than the grower can afford. CAPPA recommends two introduction rates in terms of predators per sqm., a high rate for the hot spots and a lower one for the rest of the crop. Whether or not the latter will be recommended at all depends on the season and on the number of hot spots detected. For chemical reparation selective acaricides are available, including clofentezine, fenbutatin oxide and hexythiazox. Because the spider mite / *Phytoseiulus* interaction is susceptible to the microclimate, the program might ask for some information about weather conditions and plant vigour.

Maintaining and updating an expert model is equally important as developing it. Since this was considered beyond the mission of our institute, in 1994 the further development of CAPPA has been delegated to two leading companies in the field of automation in horticulture (Priva Agro B.V., De Lier) and biological pest control (Koppert B.V., Berkel & Rodenrijs) respectively, with the Dutch agricultural advisory service DLV and our institute as advising partners (see further Altena, these proceedings).

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INTRODUCTION OF *AMBLYSEIUS DEGENERANS* FOR THRIPS CONTROL IN SWEET PEPPERS WITH POTTED CASTOR BEANS AS BANKER PLANTS

P.M.J. Ramakers & S.J.P. Voet
Research Station for Floriculture and Glasshouse Vegetables
P.O.B. 8, 2670 AA Naaldwijk, the Netherlands

Abstract
For developing an efficient method to control WFT and other thrips in glasshouses, flowering castor bean plants, *Ricinus communis*, grown in pots were colonized with the predatory mite *Amblyseius degenerans* and placed in a sweet pepper crop to operate as an open rearing system. Expansion of the predator colonies was monitored weekly. After 4 weeks predatory mites were found up to 53 plants away from the banker plant along the row, but only 5 rows across, which suggests that migration via the soil is of minor importance. Migration rate in two opposite directions (northeast and southwest) was similar. Methods for redistributing the predators are indicated.

Introduction
For the control of thrips in sweet pepper, *Amblyseius degenerans* Berlese is considered superior to other phytoseiids commercially available (van Houten & van der Staay, 1993). Still most growers are using *Amblyseius cucumeris* (Oudemans), because of the very cheap production method developed for the latter (Ramakers & van Lieburg, 1982). Some growers introduce both species, but at incomparable rates, like 1,5 million *A. cucumeris* and only 10,000 *A. degenerans*. As a result, *A. cucumeris* usually dominates at the start of the season (winter and spring), whereas *A. degenerans* needs several months to build up sufficient numbers to finally replace *A. cucumeris*. This observation has produced the rumour that *A. degenerans* is a suitable predator for the summer months only. Actually both phytoseiids can be introduced as soon as the crop produces flowers, about three weeks after planting, since both feed on pollen (McMurtry, 1977; Tognina, 1988) and continue to reproduce under short day conditions (van Houten *et al.*, 1995[a], 1995[b]). *A. cucumeris* can be introduced even earlier using an open rearing system (Ramakers, 1990), and attempts are made to introduce this predator already in the propagation houses (Visser & Lips, 1995).

In order to make *A. degenerans* more competitive, a cheap mass rearing method was developed, using flowering castor beans, *Ricinus communis* L., without prey (Ramakers & Voet, 1995). This method was presented to commercial producers of natural enemies from the Netherlands, Belgium and England in April 1994 (Anonymous, 1994), but so far this did not have a noticeable effect on prices. This paper describes an attempt to use the castor bean not just for producing predators, but as a banker plant for sustaining an open rearing of them in a sweet pepper crop (Ramakers, 1994).

Materials and methods
The experiment was carried out in a commercial glasshouse of 1.4 ha. The nearly square house was divided into equal halves by a central path. About 43,000

sweet pepper plants of the yellow variety 'Kelvin' were planted in rockwool on December 4, 1993, arranged in 'hedges' of two rows, 40 cm apart in a row. Rows were 56 m long from the central path to the glasshouse wall. The crop was trimmed weekly in order to maintain 2 main stems per plant. At the start of the experiment plants in a row as well as both rows in a hedge were touching each other, but there was no leaf contact between hedges.

Five castor bean plants containing a moderate population of *A. degenerans*, approximately 2,000 to 3,000 predatory mites per plant, were used as banker plants. They were trimmed back to the same height as the crop. The bankers were placed in the center of a hedge, so with 28 m to go to either end of the row. Bankers at the same side of the path were separated by 64 rows.

After the installation of the banker plants on February 17, the expansion of the predator colonies was observed weekly, following the protocol below:

1. Starting from the banker plant, both rows touched by it were searched in both directions.
2. Of each pepper plant 5 mature top leaves and all fully open flowers were examined.
3. If no predators were found on 5 successive plants, the rest of that row was not further searched.
4. If plants were found colonized, the neighbouring plants of the next row were searched as well.

Although the development of the thrips population was not part of the experimental setup, for the grower's peace of mind thrips was monitored with 22 yellow sticky traps (10 x 25 cm) that were replaced weekly.

Results and discussion

On the 6th day predators were found up to 15 plants away from the banker. Expansion between rows was much slower, resulting in elliptical rather than circular colonies (Fig. 1). The largest proportions (axis lengths) of a single predator colony observed after 4 weeks were 68 plants along the row, but only 8 rows across, indicating that migration from leaf to leaf or maybe via the plant supporting wires is far more important than migration via the soil. Migration towards the brighter sight of the house (southwest) was similar to migration in the opposite direction. Colonies were slightly asymmetrical towards the path, suggesting an influence of human traffic. After 6 weeks all colonies had reached both ends of the hedges, and after 7 weeks 100% of the plants in these hedges were found colonized with the protocol described above.

After 5 weeks (March, 24) the bankers were moved to new hedges opposite the first ones. The colonies expanded faster now, and the ends of the rows were reached in 5 weeks. Meanwhile predators were found on various places outside the experimental plots, probably transported accidentally by the workers and their machinery, so the systematic observations were stopped. The grower continued to redistribute the predator by taking pieces of leaf from the banker plants, since the plants had grown too big to be moved. Other growers in the area used trimmings, that are taken weekly from the pepper anyway, for the same purpose. Growers who are reluctant to leave these dead leaves on the crop, were putting sheets of corrugated paper on top of the containers with the trimmings. When these sheets were crowding with *A. degenerans*, they were cut to pieces to be scattered over the plants.

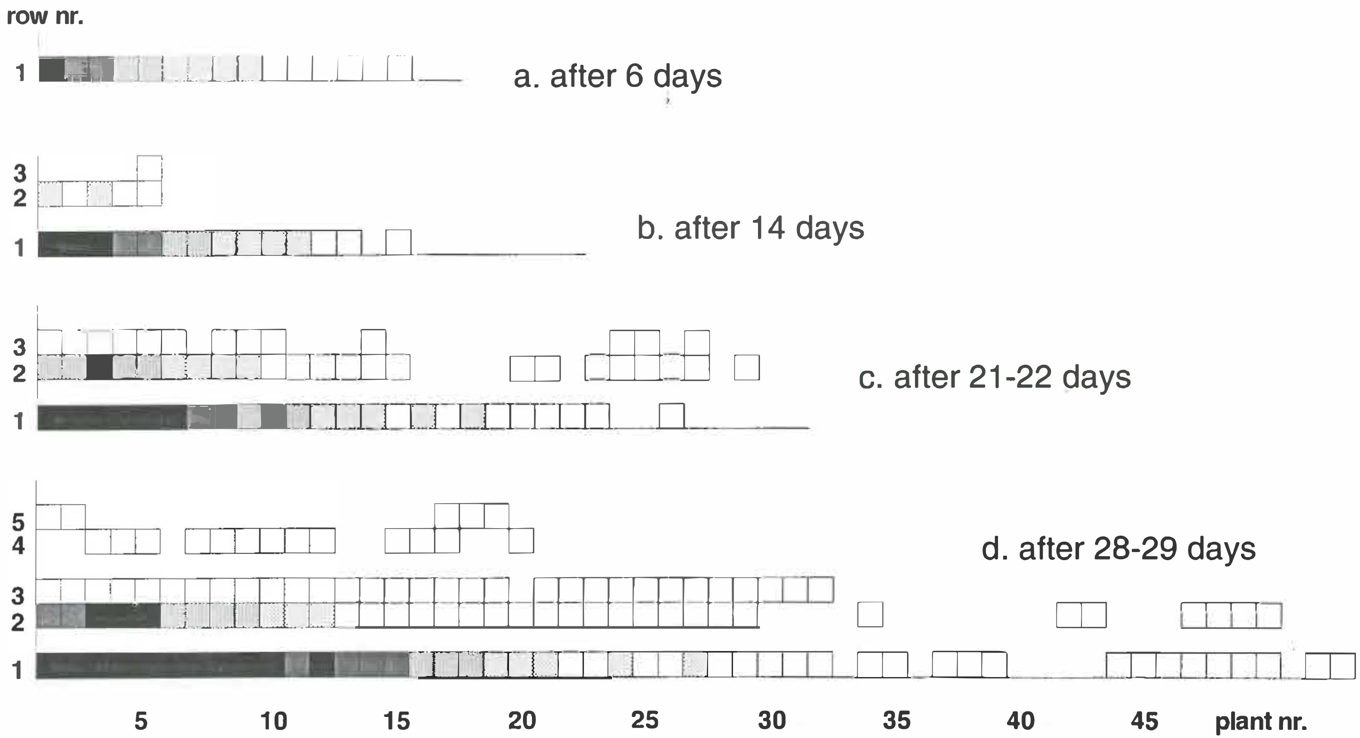

Figure 1 a-d. Expansion of *Amblyseius degenerans* colonies starting from a banker plant at the crossing of axes. Quadrant of the horizontal plane on 4 successive moments (a-d). Squares represent individual sweet pepper plants colonized by predatory mites, with the checkering indicating how often (N=20) a plant in that particular position was found colonized.

1-4 5-8 9-12 13-16 17-20

The last chemical thrips control with dichlorvos (aerosol) was carried out on February 9. The yellow traps caught 1 WFT on February 23, then no thrips during 2 successive weeks, after which a few adults were trapped every week. However, the numbers remained insignificant over the total season, with < 6 thrips (all species) per trap per week recorded until late August. The suppression of thrips cannot be attributed to *A. degenerans* alone, since the grower had introduced 7,000 *Orius insidiosus* (Say) in February. The anthocorid population developed very well, and a peak number of as many as 60 *Orius* per trap was recorded in the last week of June. Besides, *Amblyseius barkeri* (Hughes) showed up spontaneously in March, in spite of the frequent application of dichlorvos in winter, an observation that was made also in previous years on this and some other pepper holdings. For several months *A. barkeri* was more abundant than *A. degenerans* and the predator was still present at the end of the season.

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A COMBINED EXPERIMENTAL-SIMULATION APPROACH TO IMPROVE BIOLOGICAL CONTROL

H.J.W. van Roermund and J.C. van Lenteren
Department of Entomology, Wageningen Agricultural University, P.O. Box 8031,
6700 EH Wageningen, the Netherlands. Graduate School Production Ecology.
e-mail: herman.vanroermund@medew.ento.wau.nl

Summary
A model has been developed which simulates the temporal and spatial dynamics of greenhouse whitefly and the parasitoid *Encarsia formosa*. The pest-parasitoid interaction is based on the local searching and parasitization behaviour of individual parasitoids in the whitefly-infested crop. The model comprises several submodels for (a) the parasitoid's foraging behaviour, (b) the whitefly and parasitoid population development, (c) the spatial distribution of whitefly and parasitoid in the crop, and for (d) leaf production. The model will allow us (1) to explain why the parasitoid can control whiteflies on some crops and not on others in large commercial greenhouses, (2) to improve introduction schemes of parasitoids for crops where control was difficult, (3) to predict effects of changes in cropping practices (e.g. greenhouse climate, choice of cultivars) on the reliability of biological control, and finally (4) to develop criteria for the selection of natural enemies.

Introduction
Greenhouse and sweet potato whitefly (*Trialeurodes vaporariorum* and *Bemisia tabaci*) are very common, highly polyphagous pest insects all over the world. Biological control of greenhouse whitefly with the parasitoid *Encarsia formosa* has been applied with great commercial success during the past 20 years. One of the problems was that in some key greenhouse crops (e.g. tomato) results were very reliable, while on other important crops (e.g. cucumber) control often failed. Another, more recent problem, is that *E. formosa* does not seem to be a suitable parasitoid for the control of *Bemisia* and new natural enemies need to be evaluated.

We started a long-term project consisting of modelling and experimentation, with the aim to obtain quantitative understanding of this tritrophic system to explain failure or success of biological control. Because of the multitude of relationships between the trophic levels, the most important quantitative factors can only be traced after integration of all relevant processes. Systems analysis and simulation are powerful tools for this purpose. In this paper we summarize the work of the first phase, which was limited to the tritrophic system tomato-greenhouse whitefly-*Encarsia formosa*.

Direct observation experiments on foraging of *E. formosa*
When the research project started, the behaviour of *E. formosa* had been observed in various experiments. However, in many of the earlier experiments parasitoids were confined to an experimental arena, and therefore little was known about the time allocation of the parasitoid on leaves. Supplementary experiments were done in which individual parasitoids were observed continuously until they flew away, either on clean tomato leaflets, on leaflets with honeydew, or on leaflets with unparasitized and parasitized whitefly larvae (van Roermund & van Lenteren, 1995a,b; van Roermund et al., 1994). The parasitoids' residence time on leaflets, its leaving tendency and effects of temperature and of several intra-patch experiences with hosts were quantified. These data enabled quantification of the foraging process of the parasitoid from landing on a leaf until departure. The main results of this work are given below.

The parasitoid *E. formosa* searched at random on leaves. The median residence time of the parasitoid on uninfested tomato leaflets (or giving up time, GUT) was 18.6 min. Parasitoids were arrested on the leaf by encounters with, and especially by ovipositions in unparasitized hosts, by encounters with parasitized (unsuitable) hosts and by contact with honeydew. GUT since latest host encounter was again 18.6 min, also when the hosts were parasitized, but increased to 40 min after the first oviposition in an unparasitized host. The parasitoids' walking speed increased linearly between 15 and 25-30°C. The parasitoids' walking activity was very low at temperatures below 18°C and increased to about 75% of the total time on the leaf at higher temperatures. The walking activity was not affected by host encounters, but decreased with decreasing egg load after 4 ovipositions. The percentage of encounters resulting in an oviposition was about 75% for the most preferred stage (unparasitized L4 larva), but decreased with decreasing egg load.

Simulation models of foraging behaviour of *E. formosa*

The information described above was used as input in the simulation models of *E. formosa*'s foraging behaviour (van Roermund & van Lenteren, 1993, 1994; for more details see van Roermund, 1995). Here, foraging behaviour was analyzed using Monte Carlo simulation at three spatial scales: in a small experimental arena, on a tomato leaflet and on a tomato plant. Foraging behaviour was first studied at these small spatial scales, to better understand the quantitative effects of parasitoids on the whitefly population in a crop.

The simulated residence time on leaflets and the number of hosts encountered, parasitized and killed by host feeding were validated with experimental data and the simulation results agreed well with these observations. According to the model, *E. formosa* can parasitize 16 hosts per day on average at 25°C. About 7 new parasitoid eggs mature during the day (16 h) at that temperature. From the second day onwards, the parasitoid can parasitize 11 hosts per day, due to egg limitation: if the parasitoid laid all eggs the preceding day, only 4 eggs mature during the night (of 8 h) at 25°C, so the parasitoids do not have a full batch of mature eggs the next morning. The model showed that at a density of 1 L3 larva per tomato leaflet, 15.7% of the parasitoids discover the larva before they leave. Also at higher host densities, not all hosts are encountered and patches (leaflets) are not depleted after one visit. Variation in residence time and in number of encounters and ovipositions between parasitoids is considerable, mainly caused by the random encounter of hosts, the variation in handling behaviour of an encountered host and by variation in GUT.

At all spatial scales tested, the number of encounters, ovipositions and host feedings increased with host density with a decelerating rate until a maximum level is reached. This shape of the curves resembles a Holling Type II functional response, which is caused by the parasitoids' decreasing walking activity and host acceptance for oviposition when egg load decreases. This is predominant at all levels, and even a change in GUT from 18.6 to 40 min after the first oviposition on the leaf did not result in an accelerating increase of the curve. In case of a Type II functional response, percentage parasitism declines with increasing host density and parasitism is inversily density dependent. A high host density thus reduces the per capita parasitization pressure caused by one parasitoid. The effect on the population level however, depends on the balance between the parasitization pressure caused by one parasitoid and the arrestment and subsequent aggregation of parasitoids on leaves with high host density.

Life-history parameters of greenhouse whitefly and *E. formosa*

Life-history parameters of the greenhouse whitefly and *E. formosa* are reviewed in van Roermund & van Lenteren (1992a,b). Data from literature were selected on development rate of each immature stage, percentage mortality of each immature stage, sex ratio, longevity, pre-oviposition period, period of increase of daily oviposition, fecundity and oviposition frequency. With these data, the relationship between the life-history parameters and temperature were assessed by non-linear regression. Coefficients to describe the mean of each life-history parameter as a function of temperature are summarized in these papers. Coefficients of variation (*cv*: sd/mean) among individuals are also given. The coefficients are used as input in the submodels of population development of whitefly and parasitoid (see below).

Simulation model of whitefly-parasitoid interaction in a crop

The final model simulates the population dynamics of the pest-parasitoid interaction in a tomato crop (van Roermund & van Lenteren, 1995c; for more detail see van Roermund, 1995). The model simulates slow processes (time step: 1.2 h), such as whitefly and parasitoid development, leaf production, temperature fluctuation and fast processes (time step: few seconds), such as searching and parasitization behaviour of individual *Encarsia* adults on leaves. The model is unique in that it is an individual-based model which simulates local searching and parasitization behaviour of a large number of individual parasitoids in a whitefly-infested crop. The model includes stochasticity and spatial structure which is based on location coordinates of plants and leaves.

The model was validated with population counts from experiments on tomato with and without introduction of *E. formosa* in small greenhouse compartments and in a large commercial greenhouse. In both cases, the simulation results agreed well with the observations (van Roermund & van Lenteren, 1995c; van Roermund, 1995). Apparently, the hypothesized random host encounter of *E. formosa* in a tomato crop is reliable. In the model, the parasitoid does not distinguish between uninfested and infested leaflets before landing, the parasitoid searches randomly for hosts once on the leaflet, and shows a strong arrestment effect (stays longer on the leaflet) once a host is encountered.

Simulations showed that the adult parasitoid-whitefly ratio was very high and even reached 250:1. As a result, whiteflies were suppressed rather than regulated by the parasitoids at extremely low host densities (<0.3 unparasitized pupae per plant), but never became extinct. Percentage black pupae fluctuated between 40 and 70%. According to the model, the parasitoid adults reached high densities of 7.4 per plant, but due to the low whitefly density not more than 1% of the parasitoids was searching on infested leaflets.

The giving up times (GUT) of *E. formosa* vary to a large extend (van Roermund et al., 1994). According to the model, the degree of whitefly control was very sensitive to those GUT's lower than 800 s of the parasitoids. The whiteflies were suppressed at much lower densities when the parasitoids stayed *at least* five minutes on each tomato leaflet (infested or uninfested) and after each host encounter. This minimum time increases the arrestment effect and the resulting percentage of parasitoids on infested leaflets, thereby reducing the chance that clustered hosts escape from parasitism. When variation in GUT was excluded in the model, the whitefly population nearly went extinct. Variation in GUT on leaflets induces host refuges from parasitoid attack.

The model showed that when the same number of hosts were distributed over fewer leaflets (resulting in a more aggregated host distribution), whiteflies were suppressed by *E. formosa* to much lower numbers. This is caused by a stronger parasitoid arrestment and subsequent increase in the relative number of parasitoids searching on infested leaflets.

In biological control programs, parasitoids are usually tested in small-scale experiments at high host densities before introduction in the field. As a result, maximum daily oviposition of parasitoids is measured, whereas this study showed that egg storage capacity and egg maturation rate of *E. formosa* are not important for the level of whitefly control. In commercial greenhouses, whitefly densities have to be very low for biological control to be judged successful, therefore effective host searching is the most essential process. When selecting parasitoids for biological control, attention should be focused on the parasitoids' arrestment effect (minimum GUT), walking speed and activity, host acceptance for oviposition, the ratio of search times on both leaf sides and on the parasitoids' longevity, when comparing different synovigenic and solitary parasitoid species with random search. When comparing the success of *E. formosa* on different crops, attention should be focused on the same parameters, plus the whitefly development duration and the number, size and production of leaves in the canopy. The combined effect of these important factors can be tested with the model.

Epilogue

With the model we now unravelled the ability of *E. formosa* to reduce whitefly populations on greenhouse tomato. The study resulted in increased understanding of the relative importance of basic processes that affect the population interaction of whitefly and natural enemy. The life-history of parasitoids, often summarized in a r_m value, are less important than the parasitoids' searching capacity. This shows that in addition to the traditional selection criteria, a criterion based on searching efficiency is essential.

The next step in the research is to use the simulation model for other crops and evaluate the main causal factors for success or failure of biological control. When adapting the parameters in the model for gerbera and cucumber we are able to (1) explain the lower ability of the parasitoid to reduce whitefly populations on these crops, (2) improve introduction schemes of parasitoids for these crops, (3) predict effects of changes in cropping practices (e.g. greenhouse climate, choice of cultivars) on the reliability of biological control, and finally (4) to develop criteria for the selection of natural enemies. The present study already pointed at important selection criteria when comparing different synovigenic, solitary parasitoids showing random search. The model can be adapted for other parasitoids with different foraging strategies or for other natural enemies of whitefly.

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TYPES AND PURPOSES OF MODELS IN ECOLOGY AND CROP PROTECTION: AN OVERVIEW

W.A.H. Rossing, Wageningen Agricultural University, Department of Theoretical Production Ecology, P.O. Box 430, 6700 AK Wageningen, The Netherlands.

Abstract Models are mathematical tools in which knowledge about agricultural systems is integrated. Both the process of model building and the application of models increases knowledge. Based on their mathematical nature, three important categories of models comprise analytical models, simulation models, and descriptive models. Different purposes require different models. This contribution reviews major differences between models in mathematical nature and in application purpose, with illustrations from the field of crop protection. Reasons for the lack of application of models in IPM are discussed.

Introduction

A model is a simplified representation of a system and a system is a limited part of reality. Mathematical models represent numerical relationships between elements of a system. Building models is a way to draw together knowledge and to make it available for various purposes. Both process and product are important because they help to define and categorize the state of knowledge on a subject, and they help to set priorities for research by locating gaps in knowledge. At the same time models provide a means of disseminating knowledge, and a tool to make integrated knowledge operational for policy making and resource management.

There are many different types of mathematical models and many criteria to classify them, e.g. process-based *versus* statistical, dynamic *versus* static, deterministic *versus* stochastic, and spatially explicit *versus* temporal (De Wit, 1993). The character of a model depends foremost on its purpose. In this introduction to the papers on "IPM and modelling", aspects of models will be discussed from two points of view: their mathematical nature and their purpose, drawing heavily upon especially Penning de Vries & Rabbinge (1995) and Van der Werf *et al.* (1995).

Models of different mathematical nature

In crop protection ecology, three categories of models are prevalent: analytical models, simulation models, and descriptive models. These models differ in many aspects, including the level of aggregation and simplification, structure, purpose, methodology and data requirements. These three approaches could be characterized as speculative, mechanistic and correlative.

Analytical models Analytical models summarize the main components of dynamic biological systems in a few equations that characterize the rates of change of the state variables. Aim of analytical models is to study general principles underlying systems dynamics. Predictions by analytical models are usually formulated as general insights. Such predictions may be difficult to operationalize in a specific system. An example of an analytical model of interacting pest and enemy populations is the system of differential equations

$$\begin{cases} \dfrac{\mathrm{d}x}{\mathrm{d}t} = \alpha\, x - \beta\, y \\ \dfrac{\mathrm{d}y}{\mathrm{d}t} = \gamma\, y \end{cases}$$

where x is the state variable prey density and dx/dt is its rate of change; y is predator density; α is the relative growth rate of the prey population (assuming unlimited resources); β is the prey consumption rate per predator (assumed to be independent of prey density); γ is the relative growth rate of the predator population (assuming unlimited food). This simple set of equations characterizes some fundamental aspects of the interaction between spider mites and predatory mites in local patches (Janssen & Sabelis, 1992). For example, it can be shown that the prey will finally be eradicated if the initial predator/prey ratio is greater than $(\alpha-\gamma)/\beta$. This result shows how the critical initial predator/prey ratio is affected by the relative growth rates of the prey and predator populations and by the feeding rate of the predator.

Analytical models are criticized by biologists for being oversimplified, which makes their results less credible. Moreover, the mathematics involved in many papers on analytical models deters interest by biologists, especially if the results of mathematical analysis are not confronted with biologically interesting questions. Nevertheless, analytical models are a powerful tool for analysing and demonstrating general principles in biological systems.

Simulation models Simulation models are much less aggregated than analytical models. Details such as stage structure in life cycles and spatial processes, are often explicitly represented in computer code. The model integrates the processes into a 'grand picture' of the whole system. Such dynamic explanatory models enable the study of the relationship between individual traits, environmental factors and the behaviour of the system. Simulation models are system specific, and predictions are therefore not of general validity. Examples of simulation models have been presented in earlier IOBC Bulletins (e.g. de Moed *et al.*, 1990) as well as in the current issue (Van der Werf *et al.*, Van Roermund & Van Lenteren).

Three phases and a total of ten steps may be distinguished in the process of development of explanatory simulation models (Figure 1). During the phase of problem identification the problem is defined and key components and processes are identified. A useful distinction is between the ecological and technical components of a system versus the management aspects. Problem identification results in a conceptual model of the system. When the results of this first phase lead to the conclusion that all relevant information is available, the next phase is improving systems design and management. Often, more information on production ecological relations is needed, necessitating a phase of increasing ecological insight before embarking upon systems design and management (Figure 1). During the phase of increasing ecological insight, production ecological theory and experiments are used to quantify key processes, and a comprehensive simulation model is constructed. In the course of the phase of systems design and management various options for solving the problem are identified and confronted with objectives. Usually simplification of the information obtained in the previous phases in needed ('summary models').

In population-based simulation models state variables pertain to categories of individuals (e.g. eggs, leaves, fruits). An alternative approach in population models is to represent the individuals themselves and build an individual-based model (Van der Werf *et al.*, 1989). This approach is especially appropriate for systems with small numbers of moving individuals in which spatial interactions and chance processes (encounters) are of prime importance. The result of an individual-based model can be summarized in a functional response formula (Mols, 1993; Van Roermund & Van Lenteren, this issue), which, in its turn, can be implemented in a population-based model.

An important limitation to simulation models, based on state variables, is the often lengthy and poorly documented code. Strict programming discipline is important, but seldom practiced. In the process of building a simulation model it often becomes obvious that essential data are unavailable. While useful for prioritization of experimental work, knowledge caveats may frustrate the timely development and fruitful use of simulation models.

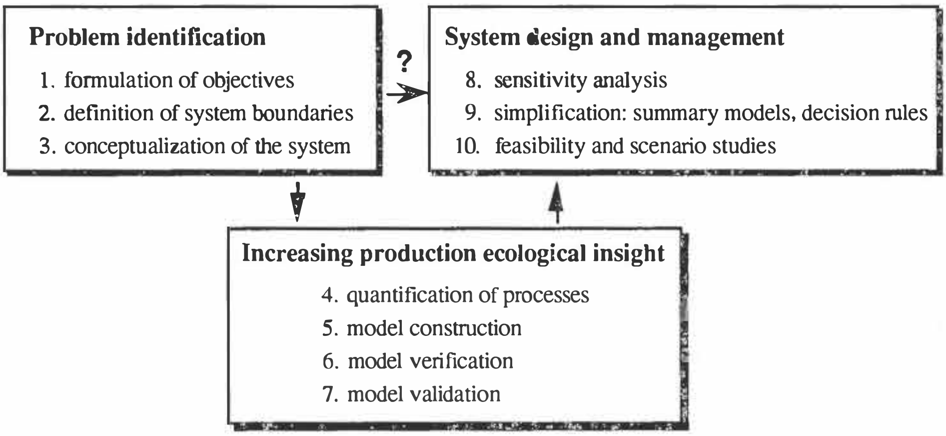

Figure 1. Developmental phases and steps in system research (after Rabbinge & De Wit, 1989).

Descriptive models Descriptive models are based on statistical analysis of data, without an attempt to unravel mechanisms underlying observed phenomena. They are complementary to analytical and simulation models. Their purpose is to predict an 'output' variable on the basis of knowledge of one or more 'input' variables. Most descriptive models are static. Examples of this are regression equations that predict disease intensity on a regional scale, based on prior weather. Daamen *et al.* (1992) predict mildew severity in winter wheat in the Netherlands as

$$y = -132 + 12\,x_1 + 10\,x_2$$

Here, y is predicted percentage of mildew-infested fields, x_1 is the average temperature in the preceding month of October (°C) and x_2 is the average temperature over the period december-March. This static regression model is based on biological and empirical insight in what are key factors in the system and on thorough statistical analysis of the data set.

Models of different purpose

Models can be useful for the development of science, for prediction and for instruction, but not all at the same time. Scientifically interesting models are often too detailed for application, while models for predictive or management purposes are often too crude or too trivial to challenge scientific interest. The categories of models described above can be compared with respect to their predictive, scientific and instructive values and their level of simplicity (Table 1).

The scientific value of a model represents the degree to which it helps us to understand the real world, to evaluate alternative hypotheses, and to suggest experiments to falsify them. The predictive value of a model represents the extent to which it simulates accurately the behaviour of a system. It measures the usefulness of the model as an instrument for application of knowledge in practice and planning, and for explorative feasibility studies. The instructive value of a model, finally, emphasizes its use in disseminating knowledge to students, extension services, farmers and policy makers. For this purpose the model should represent critical behaviour of aspects of the system in a transparent manner.

Table 1. Usefulness of different model types for different purposes. More + signs indicate greater usefulness.

Model type	Predictive value	Scientific value	Instructive value	Simplicity
Analytical	+	+++	++	++
Simulation				
• conceptual	+	+++	++	++
• comprehensive	++	+++	+	+
• summary	+++	+	+++	++
Descriptive	+++	+	+	+++

Despite its potential for prediction and instruction, the contribution of summary models to practical IPM has been limited. Most IPM systems are based solely on expertise and empirical information, and few IPM systems have been formalized into computer-based decision support systems. As a consequence IPM in new crops or upgrades of existing systems must also be based on trial and error, which is inefficient in terms of financial and natural resources. In addition, training of newcomers to IPM practice will benefit from well-structured and easily accessible information. The situation calls for closer interaction between 'producers' and 'consumers' of model-based knowledge, to exchange opportunities and constraints with the joint goal of consolidating the increasing application of IPM.

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Efficacy of natural enemies of the Western Flower Thrips Frankliniella occidentalis in Pepper flowers in the Arava Valley, Israel

Amos Rubin[1] , Orna Ucko[2] , Neta Orr[3] , Rivka Offenbach[4]
[1]Biological Control Laboratory, 14 Rahavat Ilan, Givat Shmuel, Israel
[2]Extension Service, Be'er Sheva, Ministry of Agriculture, Israel
[3]Organic Farm, Ein Yahav, Israel
[4]Arava Research and Development, Merkaz Sapir, Israel

Summary
In the winters of 1992/3, 1993/4, 40, *Orius laevigatus* was released in a protected screenhouse on flowers of organic pepper plants in Ein Yahav - at the Central Arava Valley (8.33 *O. laevigatus* on every plant). Releases from 1st of October to 23rd of December 1992, and concentrated releases in 1993 (from 22nd of September until 1st of November) did not control the huge amounts of the Western Flower Thrips, (up to 40 WFT per flower), in November-December, probably because *O. laevigatus* entered into a diapause period, and because every 10 days the peppers were sprayed with Sulphur, in order to control *Laeveillula taurica* mildew (= *Oidopsis taurica)*. In parallel, from May 1992 to November 1993 a survey was carried out on wild plants, for the presence of WFT and species of *Orius*.

In November 1995 it was observed that another common Anthocorid *Orius albidipennis* (identified by W. Kuslitzky, Plant Protection and Inspection Services, Min. of Agriculture, Bet Dagan) controlled completely the WFT, in an screenhouse of 30 % shadow, and in an open organic field of pepper. In December a culture of *O. albidipennis* was brought from these organic pepper localities into the laboratories of the Division of Entomology, Plant Protection and Inspection Services, Bet Dagan, for mass production purposes, and future releases of *O. albidipennis,* in the 50 mesh screenhouses in the fall of 1996, as this species has no diapause period in the winter. Around 1000 predacious mites of *Iphiseius degenerans (*Phytoseiidae) were released in December 1995 and January 1996 in Ein Yahav on pepper, in order to acclimatize this very promising predator of the WFT. In parallel Castor bean *Ricinus communis* were planted around the pepper screenhouses, in aim that these predator populations will be transferred by the wind to the pepper
plants.

1. Introduction
Organic pepper is planted in the Arava region, 120 km North of the Red Sea in August, harvested between November to March, and exported to Europe. In order to export "Quality A" peppers, WFT should be controlled, otherwise the silver spots caused by this pest, will cause rejection of the organic pepper, by the Israeli export authorities.

2. **Methods and Materials**

In intervals of every fortnight 50 flowers (or leaves when flower were absent) were counted in each of the 5 experimental screenhouses (three of them were of 500 m^2, with 2400 plants, and two were of 750 m^2, with 4000 pepper plants, all of them of 1195 and Maor varieties). The peppers were planted in August of 1992, and 1993 and were treated with *Bacillus thuringiensis* in control of *Laphygma exigua* and *Spodoptera littoralis* (Noctuidae) larvae. When needed, *Phytoseiulus persimilis* was released in control of the common red mite *Tetranychus cinnabarinus*.

3. **Results**

In the first season seven releases were made of the predator in with two weekly intervals, starting at 1.10.92. Between 1300 and 7000 predators were released at each date. The results of the first season (1992-3) are as follows: at the first 2 counts (29.10 and 4.11) when most of the pepper flowers were closed, only a fer WFT were seen. At the last 3 counts of November the WFT reached to a peak number of 35 individuals per flower. In the 2 last counts of December the population decreased to around 6 WFT per flower. At the first count of 1993 (2.1) no flowers were present and the number of the WFT remained low until the count of 17.3. *O. laevigatus* releases between 1.10.92 to 23.12.93, did not control the WFT, probably because *O. laevigatus* entered into a diapause period, and because every 10 days the peppers were sprayed with Sulphur, in order to control *Laeveillula taurica* mildew (= *Oidopsis taurica*).

At the count of 23.2.93 on 100 pepper flowers 106 *O. laevigatus* were seen. At 8.3.93, on 20 leaves 98 *O. laevigatus* were seen. On 28.3.93 on 50 leaves no WFT were found. At these last 2 counts no pepper flowers were around (except one single flower at the last count, where 9 WFT were found). Finally at 3.5.93 on 20 pepper flowers, 110 WFT and 11 *O. laevigatus* were present.

In the second season (1993-94) five releases were made.of the predator *O. laevigatus* , these were concentrated in a period of 40 days , and between 1000 and 5500 predators were released at each date (Starting one day before the day and the night are equal- 23rd of September- until the 1st of November). Numbers of thrips per flower during this season were on the crop were the predator was realeased: 1.2 (13.10.93), 8.8 (27.10.93), 28.2 (10.11.93) and 24.8 (25.11.93); numbers of thrips per flower in the control crop were: 1.2, 23.3, 30.1 and 36.4 on the sampling dates as above.

At this season it was observed that in flowers of pepper where the ant *Pheidole pallidulla** (Myrmicinae; identified by J. Kugler, Dept of Zoology, Tel Aviv Univ.) and Collembolla are associated with the WFT, the number of the pest is less than in flowers without these insects, perhaps because they are disturbing the activity of WFT. At Paran (40 km south of Ein Yahav and 80 km North of Eilat on the Red Sea) Orna Ucko found in 1993, the predacious mite *Amblyseius cucumeris* (Phytoseiidae) probably resistant to some pesticides, which are used in conventional pepper greenhoues. Amos Rubin found this Phytoseiid in Ein Tamar (just close to the Southern part of the Dead Sea , - 396 m under sea level) also in pepper flowers (at an open conventional field) in January 1996.

4. **Discussion**

Also at the second season of 1993-4, as in the formerly season, the predator *O. laevigatus*, did not conntrolled the WFT, because it entered to diapause at winter months of November- December, when its presence was needed, and because every 10 days the peppers were sprayed with Sulphur, in order to control *Laeveillula taurica* mildew (= *Oidopsis taurica).* Therefore, and because in another experiment (Ucko *et al.*, 1995), it was proved that mass trapping of WFT was acheived by smearing glue on blue plastics, it was decided not to release *O. laevigatus* in the following season of the fall of 1994.

5. **The present season of 1995-6**

In November 1995 it was observed that another common Anthocorid *Orius albidipennis,* controlled completely the WFT, in a screenhouse of 30 % shadow, and in an open organic field of pepper, in Ein Yahav, at the same screenhouse locality where *O. laevigatus* failed to control the huge populations of WFT, in the screenhouses of 50 mesh, in the past. (together with these *Orius* species, a third one, *niger* was also associated in organic pepper flowers of Ein Yahav). These are the most abundant species in Israel (Pericart and Halperin 1989, Chyzik, personal communication).

Therefore on the 12th and 19th of December individuals of *O. albidipennis* were brought from these organic pepper localities into the laboratories of the Division of Entomology, Plant Protection and Inspection Services, Bet Dagan, for mass production purposes, and future releases of *O. albidipennis,* in the 50 mesh screenhouses in the fall of 1996. In December 1995 it was observed that another common predator *Macrolophus costalis* (Lygaeidae; identified by T. Feller, Dept. of Zooloy, Tel Aviv Univ.) is associated with the WFT, at the organic pepper in Ein Yahav. A stock was brought to the laboratories at Bet Dagan, for future mass release program to control the WFT. A third beneficial organism is also involved in the effort to biocontrol the WFT.

More than 1000 predacious mites of *Iphiseius degenerans* (Phytoseiidae) were collected on Castor bean *Ricinus communis,* in Kfar Darom (Southern Coastal Plain) at the Gaza strip (on the 26th of December and 24th of January 1996), and released in Ein Yahav, at the biorganic pepper screenhouse of 50 mesh, in order to acclimatize this very promising predator of the WFT. In parallel Castor bean *Ricinus communis* were planted around the pepper screenhouses, in aim that these predator populations will be transferred by the wind to the pepper plants, and in absence of prey, they will survive and reproduce on pollen of castor bean (Rubin 1969).

It is hoped that these these beneficial organisms, produced by mass production in the laboratory will satisfactory control the WFT.

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Macrolophus caliginosus, FIELD ESTABLISHMENT AND PEST CONTROL EFFECT IN PROTECTED TOMATOES.

A.C. Sampson[1] and V. J. King
Ciba Bunting Ltd., Westwood Park, Little Horkesley, Essex, CO6 4BS, UK.
1. Present address: Department of Agriculture and Fisheries, P O Box 327,
Howard Davis Farm, Trinity, Jersey, Channel Islands, JE4 8UF.

Abstract

Macrolophus caliginosus was introduced in 24 Dutch greenhouses at different rates and timing. The predators established in 22 of these. Population growth was similar in all sites with a six to seven week generation time. Numbers peaked in June or July then declined in August. Predator population growth took place even in the absence of whitefly, but responded rapidly to increasing whitefly levels, thus making the initial rate of introduction less important in sites with a low pest pressure. A minimum rate of 1/m² is recommended to spread the predators around the glasshouse, but 2/m² may be required in sites with an existing pest problem or a history of pest attack. Establishment occurred from introductions made in weeks five, 15 or between, but because of the long generation time, introductions were most cost-effective when made before March. *M. caliginosus* complemented existing biological control programmes and contributed greatly to mid-season control of whitefly, spider mite and caterpillars.

Introduction

The predatory bug, *Macrolophus caliginosus* (Wagner) was developed commercially for the control of glasshouse whitefly, *Trialeurodes vaporariorum* and tobacco whitefly, *Bemisia tabaci* in Southern Europe (Malausa *et. al.*,1987). Under Mediterranean conditions *M. caliginosus* helped to control high populations of whitefly in tomatoes, and also suppressed spider mite, aphid, caterpillar and other pest populations (Fauvel *et. al.*,1987).

Field trials were set up in the Westland area of Holland in 1994 in collaboration with Brinkman bv, to monitor the establishment and pest control effect of *M. caliginosus* in Northern Europe, which is outside its natural range, and where there is a lower pest pressure than in the Mediterranean. Different rates, strategies and timings of introduction were compared.

Methods

M. caliginosus was introduced to 24 commercial greenhouse tomato blocks between week five (early February) and week 15 (mid-April). All plants were past the second truss stage and grown according to usual grower practice. Single or split introductions of between 0.5/m² and 3/m² were made (Table 1).

Table 1: *M. caliginosus* introduction rates and strategies

No./m² introduced in four successive weeks	Number of sites	Week number of the first introduction
0.5, 0, 0, 0	2	7, 7
1, 0, 0, 0	3	7, 9, 15
0.5, 0, 0, 0.5	2	6, 8
1, 0, 0, 1	7	5, 5, 5, 8, 10, 10, 15
2, 0, 0, 0	8	5, 5, 6, 6, 8, 9, 11, 15
2, 0, 0, 1	2	6, 8

Commercially produced adults, packed in woodwool were released. Females were mature and on the point of egg laying. Adults were spread evenly around each block by walking down each row, allowing *M. caliginosus* to hop or fly onto the tomato plants. *Encarsia formosa* was also introduced at the beginning of the season but introductions were stopped once *M. caliginosus* had established. At each trial site 16 plants were chosen and marked at random. These plants were monitored every two weeks until the end of May, then once in July and once at the end of August. The entire plant was examined and the number of *T. vaporariorum* (adults, pupae and fourth instar larvae), *E. formosa*, (parasitised scales) and *M. caliginosus* (adult and nymphs) recorded. The presence or absence of plant damage was also noted.

Results

Predator Establishment

M. caliginosus established well in 22 out of 24 sites. The pattern of population growth was similar at most trial sites (Figure 1). The first nymphs appeared three to four weeks after introduction reaching adulthood in six to seven weeks. The first large increase in numbers occurred 12 to 14 weeks after introduction. Generations had overlapped by this stage since some adults initially released were still alive when the second generation adults appeared. Populations peaked in late June or July then declined during August.

The number of *M. caliginosus* per plant in the second generation six weeks after introduction was proportional to the introduction rate (Figure 2), but by 12 weeks, there was no significant difference ($p = 0.55$), with numbers averaging four per plant. The height of population peaks during the season was related to the whitefly population in the block, regardless of the initial introduction rate (Figures 3 & 4). Populations peaked at an average 31 individuals per plant across all sites. Peak numbers per plant ranged between an average of nine to 68 per plant between sites, and 0 to 168 on individual plants, the largest numbers being on plants which were heavily infested with whitefly. No plant damage from *M. caliginosus* was observed on any plants.

The effect of splitting a single rate into two introductions at a three week interval delayed establishment by a week but there was no significant difference between the height of population peaks ($p = 0.74$).

M. caliginosus established whether introduced at week five, 15 or between. Earlier introductions were slightly slower in developing but provided a longer period of crop protection (Table 2).

Table 2. *M. caliginosus* establishment at four sites when introduced at 2/m² in weeks five, eight, 11 and 15.

Week No.	Number of Macrolophus per plant by week number									
Introduced	7	9	11	13	15	17	19	21	27	35
5	0.1	0.2	0.3	1.4	0.6	2.9	4.6	10.4	33.0	17.2
8	-	0.0	1.1	2.1	3.0	4.3	5.4	10.7	34.0	14.4
11	-	-	-	0.0	0.3	0.8	1.1	2.3	18.4	10.0
15	-	-	-	-	-	0.0	0.4	1.4	24.2	1.4

Establishment failed at the two sites where *M. caliginosus* was introduced at 0.5/m². Harmful pesticides were used to reduce a developing whitefly population at one site, and it is thought that spray drift from a neighbouring flower nursery affected establishment in the second.

Figure 1: Establishment of Macrolophus and whitefly populations, showing the average numbers per plant from all sites.

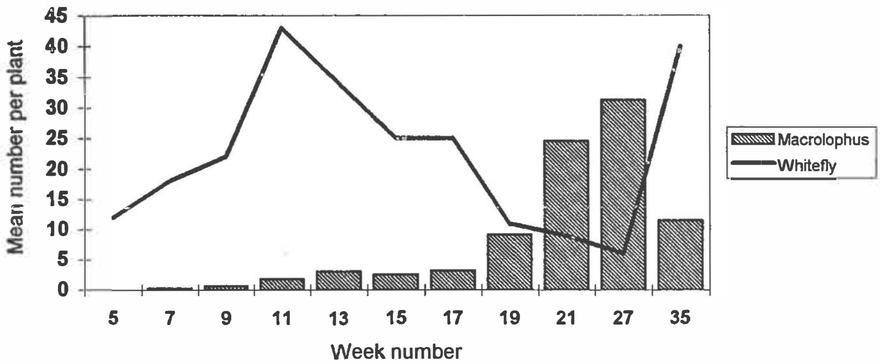


Figure 2: Macrolophus numbers six weeks after introduction.

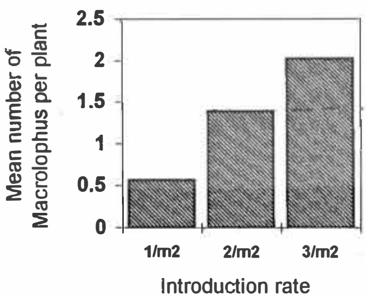


Figure 3: Peak numbers of Macrolophus during the season.

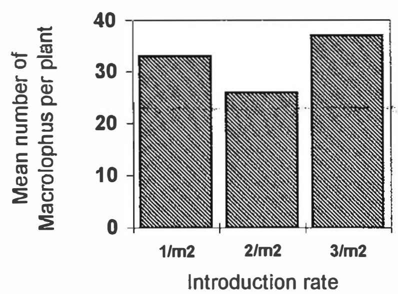
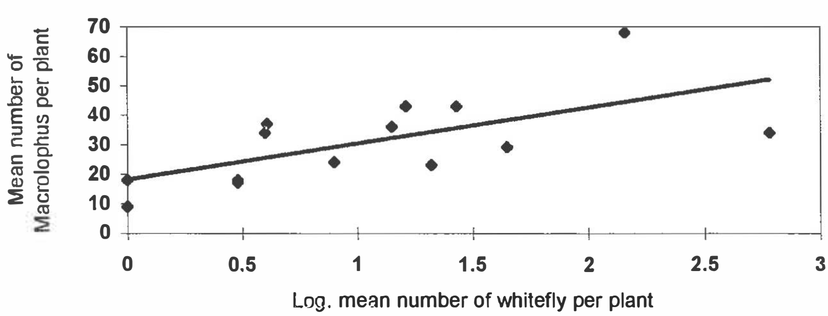


Figure 4: Comparison between peak numbers of whitefly (all stages) and Macrolophus per plant at the different trial sites.



Pest Control Effect
At 13 of the trial sites whitefly populations were low at the time of *M. caliginosus* introduction, and remained below ten scales per plant from February to the end of July. Numbers increased only after *M. caliginosus* numbers declined in August. At nine sites, whitefly numbers continued to increase after predator introduction but declined during April once *M. caliginosus* had established (Figure 1) Pesticide intervention was used at two sites. Early season control was aided by *E. formosa*, with an average total of 14/m² being used throughout the season. *M. caliginosus* also suppressed other pests including ***Tetranychus urticae*** and ***Lacanobia oleracea***, allowing the number of other inputs such as *Phytoseiulus persimilis*, *E. formosa*, *Bacillus thuringiensis*, fenbutatin oxide (Torque), and buprofezin (Applaud), to be reduced. At one nursery pest control treatments were reduced by 70% compared to an adjacent block without *M. caliginosus*.

Discussion
Establishment in Northern European tomato crops followed the same pattern as in Southern crops (Trottin-Caudal and Millot, 1994). Populations built up in mid-summer when temperature, light and food availability were optimum, declining again in August in response to reduced pest levels and falling light levels. Predators established in sites with a low prey density, but it is likely that adult fecundity and survival was affected. Fauvel, et. al. (1987) found that an adult female needed a minimum of 50 whitefly eggs to maintain full fecundity, and prey levels in Dutch tomatoes were often less. Where whitefly levels increased, *M. caliginosus* showed a rapid response. At sites with low prey levels, it would appear that there is little advantage in introducing a rate above 1/m² as development is limited by food availability. One per m² is considered the minimum needed to distribute the predators around a block, higher rates are only merited if there is a history of pest attack or an existing pest problem. The rate response in the second generation was observed because fully fecund adults were introduced, laying their full complement of eggs. Introduction of nymphs may delay establishment in low prey situations, as developing adults would lay fewer eggs.

As development time is long, the grower gains most crop protection and value for money from early introductions, preferably before March. *E. formosa* should be introduced to protect the crop from whitefly until *M. caliginosus* has built up. Split introductions offer no direct benefit under ideal conditions, but may provide some security if the quality of the predators is under question or where pesticide residues are suspected. The predator appears to be compatible with existing biological programmes in protected tomatoes. It is popular with growers for its voracious appetite, visibility in the crop and cost saving contribution to mid-season pest control.

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INTEGRATED BIOLOGICAL CONTROL OF LEAFMINERS, LIRIOMYZA TRIFOLII, ON GREENHOUSE CHRYSANTHEMUMS

Roger B. Sher & Michael P. Parrella
Department of Entomology, University of California, Davis

ABSTRACT
The entomopathogenic nematode, Steinernema carpocapsae, and the parasitoid, Diglyphus begini, are both potential biocontrol agents for the leafminer, Liriomyza trifolii. Neither agent alone, however, has proven to be control or cost-effective in ornamental greenhouse production of chrysanthemums. A combined program utilizing both agents may be warranted, but detailed information on potential interferences needs to be gathered before adequate scheduling of releases can be developed. We have found both positive and negative interactions between these agents. From a positive viewpoint, adult female wasps are able to detect and avoid ovipositing on nematode infected hosts, and paralyzed leafminer larvae, the wasp egg/larva food source, have a lower susceptibility to nematode infection that do healthy larvae. Negative interferences are also seen, however, with nematodes decreasing the likelihood of wasps developing to adults and nematodes directly infecting and killing wasp larvae.

INTRODUCTION
In the early to mid-1980's, the leafminer, Liriomyza trifolii, was a major pest of numerous floricultural crops. This leafminer was a serious problem on cut and potted chrysanthemum and on numerous species of bedding plants. Innovative pest management strategies were developed to assist growers in their efforts to combat this pest (Parrella & Jones, 1987). The use of multiple tactics to control this leafminer (including cultural, physical, mechanical, biological and chemical controls) is a common sense approach, and one that will provide long term control without selecting for resistance to any of the control options. While this appears very reassuring, it is clear that many growers are relying solely on the use of abamectin to keep this pest under control; many growers apply the material on a weekly basis. The product cannot survive when used in such a way given the propensity of L. trifolii to develop resistance to insecticides. A disturbing fact is that there is no insecticide currently on the market or that will be registered in the near future with the leafminer control capability of abamectin. Thus if we begin to see wide scale failure of this product for leafminer control, growers will have nowhere to turn.

There are potentially viable biological control agents that can be used for leafminer control. The problem lies in the need to achieve very high levels of control because of the aesthetic value of floriculture crops and to obtain this economically. For some natural enemies such as the parasitoid Diglyphus begini, acceptable control can be achieved with repetitive releases of large numbers of parasitoids which is not economical. For other biological control agents such as the entomopathogenic nematode, Steinernema carpocapsae, releasing large numbers on a regular basis is inexpensive but does not provide the necessary control. We suggest that the solution may be to use these natural enemies together for biological control of this leafminer. This report details some of the ongoing research in our laboratory on the ecological and behavioral interactions between these two biological control agents.

MATERIALS AND METHODS

Insect Colonies: Colonies of both L. trifolii and D. begini were maintained in greenhouses on the campus of The University of California at Davis according to methods detailed in Parrella *et al.* (1989).

1. Oviposition choices by adult female D. begini:

a) Eight individual leaves with 6 day old leafminer larvae were taken from one plant in the leafminer colony greenhouse and divided into two groups of four. One group was sprayed with water and 0.1% Triton-X (surfactant), the second group was sprayed with water, 0.1% Triton-X and infective juveniles of S. carpocapsae. Both groups were kept in covered petri plates with moist filter paper for 24 hours. After 24 hours, leaf discs (20 mm diameter) were punched from the leaves, each containing one leaf mine with either a healthy larva or a nematode infected larva. Pairs of discs with one healthy and one infected larva were then placed side-by-side on moist filter paper in 60 mm petri plates. Two adult female D. begini wasps were then placed in the petri plate and allowed to remain undisturbed for either 2 or 24 hours, 2 plates per time period. At the end of the exposure time, the wasps were removed and the leaf mines were dissected and examined for the presence of wasp eggs. This design was repeated with larvae 48 hours after nematode application. The experiment was repeated 4 times, for a total of 32 pairings.

b) The design was the same as above, except that two or four adult females were used and all were left in the petri plates for 24 hours. Again, this design was repeated with larvae 48 hours after nematode spray. The experiment was repeated 5 times, for a total of 40 pairings.

2. Nematode Infection of D. begini larvae and adults:

a) Fifty 5-day old D. begini larvae were removed from leaf mines and 10 each were placed in each of five 60mm petri plates with filter paper. The filter paper was then saturated with 0.5 ml distilled water with infective juveniles of S. carpocapsae at either 0, 100, 500, 1000, or 5000 nematodes/ml. All larvae were held for 48 hours and then dissected and examined for the presence of nematodes. This experiment was repeated twice for a total of 10 petri plates.

b) Twenty-five hand punched 22 cm diameter leaf discs containing one mine with one wasp larva in the center of the disc were placed in each of twenty-five 60mm petri plates with filter paper. The leaf disc surface was then sprayed with 0.5 ml distilled water with 0.1% Triton-X and infective juveniles ranging from 0 to 5000 nem/ml, as above. All larvae were held for 48 hours and then dissected and examined for the presence of nematodes. Five petri plates were used per nematode concentration, and this experiment was repeated twice for a total of 50 petri plates.

c) Five adult D. begini were placed in each of nine 60mm petri plates on filter paper. Adults and filter paper were then directly sprayed with 0.5 ml of nematode solution, at three concentrations variously ranging from 0 to 3200 nem/ml. All adults were held for 48 hours and then dissected and examined for the presence of nematodes. Three plates were used per concentration and the experiment was repeated 6 times for a total of 54 plates.

3. Development of D. begini eggs in the presence of nematodes:
Seven day old leafminer larvae were exposed to the parasitoid colony for 4 hours or 24 hours, and leaves were then removed. Mines were dissected and one parasitized host larvae with the associated parasitoid egg was then placed in an artificial mine (Heinz & Parrella, 1989).

Individual artificial mines were exposed to one of three treatments: no extra water added (control), a small drop of water (water treatment), or a small drop of water with 5 infective juvenile nematodes. All mines were held until death of the wasp larva or pupa, or until the wasp emerged as an adult.

Fifteen artificial mines each were set up per replicate for the 4 hour old wasp eggs and fifteen for the 24 hour old wasp eggs, with 5 mines each receiving one of the three treatments. The experiment was repeated 4 times for a total of 120 mines.

RESULTS

1 . Oviposition choices by adult female D. begini:
The number of eggs laid on either healthy or nematode infected hosts in the choice tests was not significantly different between treatments ($p=0.068$), but this may be due to the very low numbers of eggs laid overall. Only 11 eggs were recovered from the leaf discs, with 10 of them being found on the healthy larvae.

2. Nematode Infection of D. begini larvae and adults:

a) When wasp larvae were removed from mines and placed directly onto filter paper, even at the lowest concentration of nematodes (100/ml), 100% mortality of larvae was observed after 48 hours.

b) With wasp larvae partially protected inside leaf discs, the highest infectivity, 60%, was seen with 5000 nem/ml. Infectivity at 100, 500, and 1000 nem/ml all averaged around 40%.

c) Although several adults did die over the 48 hour testing period, subsequent dissection studies indicated that none of them died from direct infection by the nematodes. The cause of death in most cases was either infection by fungi or drowning in moisture droplets forming on the lower face of the petri plate lid.

3. Development of D. begini eggs in the presence of nematodes:
Overall, there was no significant block ($p=0.774$) or age of egg ($p=0.21$) effects. but there was a significant treatment effect ($p=0.016$). There was no significant difference ($p=0.743$) in the percentage of eggs that emerged as adults between the control treatment (45% $\pm$ 9) and the water only treatment (40% $\pm$ 6), but there was a significant effect ($p=0.009$) between control and nematodes (12.5% $\pm$ 5) and between water only and nematodes ($p=0.018$).

DISCUSSION

The experiments described are a small part of the overall picture on the ecological interactions between D. begini and S. carpocapsae, but already we have begun to see both positive and negative aspects to their combined use for control of L. trifolii. We have found that wasp larvae inside leaf mines are somewhat protected from nematode infection, and that adults are completely immune to nematodes. In addition, adult female wasps seem to detect and avoid ovipositing on the infected leafminer larvae. Observational studies have also indicated that female wasps do not lay eggs on infected hosts, but that they will host-feed, and that this does not have any mortality effect on them. On the negative side, we see that the wasp larvae are susceptible to nematode infection, and that the presence of nematodes inside mines with wasps eggs decreases the wasps probability of surviving to adulthood. Whether this is due to direct infection of the newly hatched wasp larva or indirect infection of its food source is presently being determined. We have found that paralyzed leafminer larvae are much less accessible to nematode entrance than are healthy larvae. If the mechanism of reduced adult emergence is indirect infection, therefore, a wasp egg on a paralyzed larva may not be very threatened. Again, the mechanism of reduced infection of paralyzed larvae is presently being studied. It may be a behavioral avoidance by the nematode due to lack of CO^2 cues, a mechanical barrier to nematode penetration such as closing of spiracles, or a toxicological reaction of the wasp venom. Once the major positive and negative effects on both the nematode and wasp populations due to their interactions are determined, this information can be used to properly develop a spray and release timing schedule of the two agents. It may be that the judicious timing of nematode applications that minimizes negative interference with the wasp population will allow for improved control of the pest over that presently seen by either agent alone.

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ECONOMIC INJURY LEVEL AND IMPACT OF WESTERN FLOWER THRIPS ON PLANT PRODUCTIVITY OF GREENHOUSE SWEET PEPPER

J. L. Shipp[1], M. R. Binns[2] and A. P. Papadopoulos[1]
[1]Agriculture and Agri-Food Canada, Research Centre, Harrow, Ontario, Canada N0R 1G0
[2]Agriculture and Agri-Food Canada, Central Experimental Farm, Ottawa, Ontario, Canada K1A 0C6

Abstract
The economic injury level for thrips-damaged fruit and the impact that different densities of western flower thrips have on individual plant productivity was determined for greenhouse sweet pepper. The study was conducted from November to August, 1993-95 in three greenhouses at the Harrow Research Centre using the cultivar 'Cubico'. Population densities of thrips were monitored weekly using yellow sticky traps and plant tappings. Mature fruit were harvested weekly, graded, weighed and assessed for thrips damage. Flower and developing fruit counts, plant height and photosynthetic rate were used to measure plant productivity. A mean density of 15-20 adult thrips per sticky trap per day or 8 adult thrips per plant tapping would result in the occurrence of unmarketable fruit. This density did not cause a reduction in fruit yield. Individual plant productivity was affected only under high thrips densities.

Introduction
Western flowers thrips (*Frankliniella occidentalis* (Pergande)) is a major pest of greenhouse sweet pepper in Canada. This pest causes direct damage to the fruit as a result of feeding and oviposition on developing fruit and indirect damage by feeding on the leaves. Control strategies for this pest consist of strict sanitation measures, biological control agents and pesticides (Shipp *et al.*, 1991). In Ontario, many growers still use pesticides on a regular basis because of the invasion of minor pests, such as European corn borer (*Ostrinia nubilalis* (Hübner) and *Lygus* bugs, for which there are no effective commercially-available biological control agents. A precision-level sampling program has been developed for monitoring and predicting the population densities of this pest on greenhouse sweet pepper (Shipp & Zariffa, 1991). Therefore, the next step is to determine the economic impact of different population densities of *F. occidentalis* on sweet pepper and to use this information to determine economic injury levels (EIL) for this pest.

Materials and Methods
The study was conducted in three greenhouses at the Harrow Research Centre and replicated over two growing seasons from November to August, 1993-95. The greenhouses were 10 x 16 m in size with a planting density of 312 plants per greenhouse. The commercial cultivar 'Cubico' was used and grown according to commercial practices. Each greenhouse was exposed to different pest densities (low, moderate and high) by introducing zero, one or two adult thrips per plant, into each of the three greenhouses respectively, when the crop was transplanted into the greenhouse in November. The population densities of the thrips were monitored weekly using yellow sticky cards (13 x 8 cm) and plant tappings. Each greenhouse was divided into four quadrants with one sample per sampling method collected weekly in each quadrant.

Once fruit were ready to be harvested (ie., ≥ 80% red), fruit were harvested weekly by quadrant and greenhouse. All fruit were individually graded for size (small, medium, large, extra large and unmarketable) and weighed. The fruit was then assessed for thrips damage to the complete fruit. A rating scale of 1-3 was used; where 1= essentially no damage, 2= moderate damage and 3= heavy damage.

For measurement of individual plant productivity, four randomly-selected plants within each quadrant were observed weekly for plant height and flower and fruit counts. Any mature fruit on these plants were harvested and labelled according to greenhouse, quadrant and plant number. The fruit were then graded, weighed and rated for thrips damage. Photosynthetic measures were also recorded for individual leaves on another four randomly-selected plants per quadrant. Photosynthetic measurements were recorded four to six times over the season.

To determine the EIL, the mean number of thrips-damaged fruit, which could not be sold as number 1 grade, per plant at harvest were plotted against mean weekly densities of adult *F. occidentalis* for the two sampling methods (ie., from 0-7 weeks before harvest). The data are currently being analyzed for adult thrips-days *versus* thrips-damaged fruit. EIL will also be determined for larval *F. occidentalis.*

Results and Discussion

The seasonal trends for adult *F. occidentalis* as monitored by the yellow sticky cards and plant tappings were similar both growing seasons. Mean thrips densities over the seasons ranged from approximately 4-10 adult thrips per sampling method for the low treatment, 15-22 for the moderate and 20-34 for the high thrips density in 1994 and from 1-2, 6-17 and 18-22 for the low, moderate and high thrips densities respectively in 1995 for the two sampling methods. Thrips densities for the specific treatment levels fluctuated considerable throughout the season. The release of biological control agents, such as *Amblyseuis cucumeris* (Oudemans), and periodic pesticide applications were used to try to maintain three different treatment levels.

With respect to fruit harvest, peppers were harvested from March to August each year. The grades were grouped by extra-large, large and medium *versus* small. This grouping was used because extra-large, large and medium all received the same premium price, whereas small fruit received a substantially lower price per kg. Trends of weekly and cumulative yield for the three treatments were essentially similar over the 1994 season with no obvious differences in yield. Although, for the first half of the season, the high thrips-density greenhouse had a slightly lower cumulative yield. This reduction in yield occurred at the same time that the highest treatment level had its greatest pest densities. For 1995, however, a substantial difference in cumulative yield was found between the high thrips-density treatment and the low and moderate thrips-density treatments during the latter half of the season.

For thrips-damaged fruit, the cumulative mean numbers of fruit per plant for each damage category were plotted individually against harvest date and with categories one and two combined. The first two categories were combined because these ratings did not seem to affect the marketability of the fruit. A damage rating of three, however, resulted in fruit that were categorized as the same as for fruit that were graded small. For 1994, the greatest number of ones and twos occurred in the low and moderate thrips-densities greenhouses, while very few threes were found under the moderate thrips-density and essentially none in the low thrips-density treatment (Fig. 1). For a damage rating of three, a cumulative mean of 3.5 fruit per plant occurred under the highest treatment. A similar relationship was found for fruit that were harvested during 1995. The EIL for adult thrips-damaged fruit (F3) was approximately 15-20 thrips per sticky trap or 8 thrips per plant tapping for both seasons.

With respect to the impact of different thrips densities on individual plant productivity, plant height was slightly higher throughout the season for plants that were grown under the low thrips-density treatment compared to the other treatments during 1993-94. For flower and fruit counts, patterns were similar for all three treatments. For 1994-95, plants from the high thrips-density greenhouse had the lowest plant heights during the middle of the season and then caught up. Fruit counts were also the lowest during the same time period in the high thrips-density greenhouse, while the pattern for flower counts was similar for all treatments during 1994-95.

Thrips density was fairly constant in the high thrips-density greenhouse until near the end of the June when the density decreased significantly.

With regard to photosynthetic measurements, in 1994 the recordings for photosynthesis were quite variable between quadrant and greenhouses. The variability was actually too great to form any conclusions. Incidence light level has a major influence on the readings and in 1994, light levels in the greenhouses were too variable when the measurements were made. In 1995, all readings were made between 1000 and 1400 h and on only sunny days to ensure optimal light conditions. For the 1995 growing season, differences were found in the photosynthetic rates among the three treatments (Table 1). As the season progressed, the photosynthetic rate was significantly lower for plants grown in the high thrips-density greenhouse. This was also the time period when yield was reduced in the high thrips-density greenhouse.

Conclusions

The EIL for *F. occidentalis* on sweet pepper is lower for fruit damage than for yield reduction. The standard sampling method used by growers for monitoring thrips is sticky traps. When thrips densities reach a mean of 15-20 thrips per trap per day, growers can expect a proportion of their fruit to exhibit thrips damage that will be great enough to make the fruit unmarketable as number 1 grade. In 1994 and 1995, a cumulative mean loss of 2.5-3.5 fruit per plant at a fruit weight of 175-235 g per fruit was found which can translate into a sizeable loss when you consider there are 25,000 plants per hectare. At an average price of $4 and 1 per kg for number 1 and 2 grades respectively in 1995, this fruit loss would result in an economical loss of $38-72 K per ha. With further data analysis, the EIL will be determined for yield reduction and for larval thrips densities. Also, under high population densities of *F. occidentalis*, this pest impacts upon plant growth parameters such as photosynthesis, height and fruit development. Further analyses should better clarify this relationship, but this area deserves more research especially with set levels of thrips densities on individual plants.

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Table 1 Mean photosynthetic rate (μmol/m²/s) for greenhouse sweet pepper exposed to three population densities of *F. occidentalis*

	Thrips Densities		
Date	Low	Moderate	High
1 & 2 Mar.	15.35 + 0.54a	13.90 + 1.10a	14.28 + 2.38a
11 & 12 Apr.	22.45 + 1.59a	20.23 + 0.96a	20.49 + 1.38a
6 & 12 Jun.	9.27 + 0.34a	9.16 + 0.61a	6.95 + 0.23b
19 & 26 Jul.	8.68 + 0.36a	8.05 + 1.37ab	7.01 + 0.10b

Mean photosynthetic rate is an average of 16 plants per treatment.
Means in a row followed by the same letter are not significantly different ($P < 0.05$, ANOVA and DMRT).

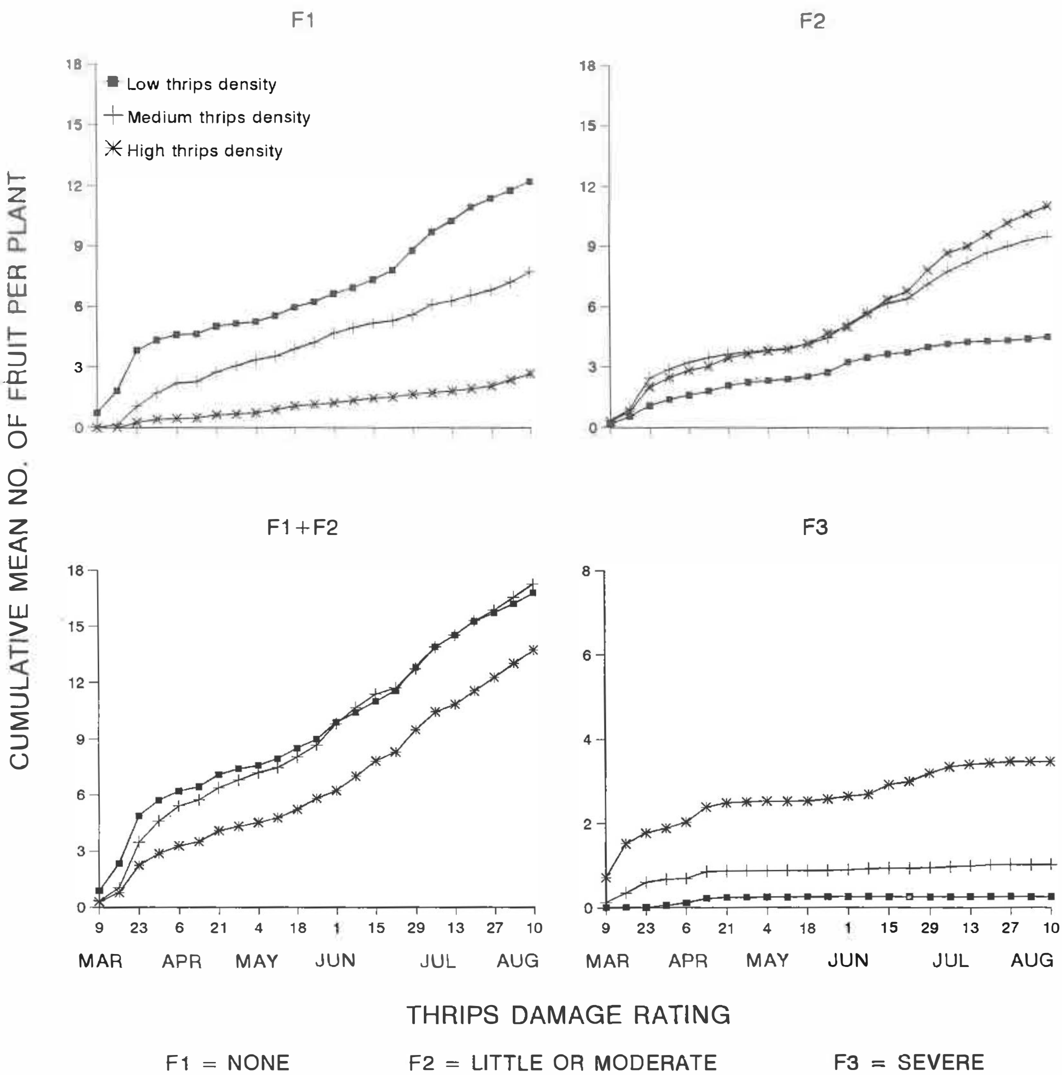

Fig. 1. Cumulative mean number of thrips-damaged fruit (extra large, large and medium) per plant at three pest densities for greenhouse sweet pepper from March to August, 1994

HARROW GREENHOUSE CROP MANAGER: A DECISION-SUPPORT SYSTEM FOR INTEGRATED MANAGEMENT OF GREENHOUSE CUCUMBER AND TOMATO

J. L. SHIPP[1], N. D. CLARKE[2], A. P. PAPADOPOULOS[1], W. R. JARVIS[1], T. J. JEWETT[1] AND S. K. KHOSLA[3]

[1]Agriculture and Agri-Food Canada, Research Centre, Harrow, Ontario, Canada N0R 1G0
[2]AI Solutions, 47 Tomlin Cres. Richmond Hill, Ontario, Canada L4C 7T1
[3]Ontario Ministry of Agriculture, Food and Rural Affairs, Research Centre, Harrow, Ontario, Canada N0R 1G0

Introduction

Decision-support systems (DSS) can provide a useful role in agriculture at all levels (ie. grower, industry, extension, research and education). These user-friendly interactive programs can provide advice, assist in problem-solving and help understand how agricultural systems function (Crassweller *et al.*, 1993). Several factors make the greenhouse industry a logical candidate for utilization of DSS. 1. Greenhouse growers are constantly inundated by new information for all aspects of production. However, growers first must find the information, understand what it means and then integrate this information into their own commerical operation. Often the result is information overload. The DSS provides and organizes all this information, including substantial information that was only previously present in the minds of the experts, at the fingertips of the user 24 hours a day. 2. The greenhouse industry is very technologically-advanced with computerized environmental control and fertigation systems in wide-spread commercial use. The result is a high percentage of computer ownership and literacy among growers. 3. Consumer demand for pesticide-free and high quality product in conjunction with strict environmental regulations, fewer effective registered pesticides and worker health concerns are forcing the industry to improve management practices by reducing the use of chemicals for pest control and in reduction of fertilizer and water use for crop production. These strict demands can be met for greenhouse production because the crops are grown within an enclosed environment, biological control agents are commercially available, cultural control strategies are available and soilless and closed-feeding productions systems are used. However, substantial expertise is required to integrate all these management components and that is where DSS are useful.

For greenhouse crops, expert systems or DSS have been developed for pest diagnosis and control, climate control, scheduling and managing production practices and accounting of production costs. The majority of these systems deal with disease management, climate control or specific aspects of production. At Harrow, it was decided to develop a holistic approach to greenhouse crop management because many of the practices or recommendations for one area can have a direct impact on other aspects of production. The objective of the "Harrow Greenhouse Crop Manager" (HGCM) is to develop a DSS for integrated crop management that will improve fruit yield and quality while at the same time reduce energy consumption by optimizing greenhouse environment and fertilizer application, and eliminating pesticides through the use of non-chemical pest management strategies. This objective is to be achieved while maintaining acceptable and profitable production levels.

The various components of the HGCM are presented in Fig. 1. There are five knowledge-based modules containing rules and facts acquired from the experts and literature to solve a particular task and three additional modules (interface, initialization and information) (Clarke *et al.*, 1994a). The HGCM originally started as an expert system, but quickly expanded to a DSS with hypertext information on all aspects of production, pictorial keys to disorders, an ability to record and manipulate data and plot it in tabular or graphical format and programs to assist the user in determining VPD or dewpoint, fertilizer concentrations and demonstration of the use of a computer-controlled fertigation system. An interface is also being currently developed that will allow the DSS to access climate data that is generated by the climate control systems. This information will be useful in forecasting and preventing disorder outbreaks. The HGCM operates on a 386 or higher personal computer and Microsoft Windows. At the present time, the systems occupies approximately 30 megabytes on the hard drive.

Development of HGCM

Initial Idea

The plan to develop the DSS originated with the researchers at the Harrow Research Centre. The initial idea was the result of experiences that the researchers had with growers with respect to greenhouse problems and the implementation of new technology. It was felt that we were at a point where it was necessary to integrate management practices for greenhouse production to avoid conflicting recommmendations that were counter-productive for the grower. Also, a better way was needed for transferring new and old technology to growers to provide fast and accurate answers to their problems. The growers were trying to reduce pesticide, fertilizer and water use and, as a result, improve yield and fruit quality. The ultimate aim was to improve the competitiveness of Ontario and Canadian growers for market expansion into the United States.

All researchers, extension advisors, industry and growers agreed on the nature of the problem and that it had to be addressed in some manner. However, not all growers initially saw the benefit in the DSS. First, DSS were new to them and there was no reason to expect growers to immediately understand how they work. Some growers felt that they did not not need any help and that they can do everything themselves. Often, these growers used pesticides on a regular basis. Some extension advisors and industry personnel were skeptical of the usefulness of the DSS as the advisor already does this now. Therefore, it is important to educate all players initially about what a DSS is, how it is developed, why the greenhouse industry is a good candidate and how the users will benefit from using the system.

Even though the DSS will greatly help the grower address their problems, it is not the final answer to their problems. In Ontario, the researchers, extension advisors and industry personnel continue to hold workshops and educational sessions, publish technology transfer articles, conduct demonstration trials on and off the Harrow Research Centre and make personal visits to the growers. All these activities are still needed in addition to the use of a DSS. As well, new research results are continually being incorporated into new versions of the DSS.

Study of Feasibility and Desirability

A steering committe has been formed to guide and evaluate the development of the HGCM. This committee consists of researchers, extension advisors, growers and a knowledge engineer. Four researchers were selected representing the areas of entomology, plant pathology, production and greenhouse engineering. The backgrounds of the two extension advisors are pest management and crop production. Also, eight cucumber and nine tomato growers have been selected to give a cross section of the productions practices that are being implemented commercially. The cucumber and tomato steering committee meet separately.

The role of the researcher in the development of the HGCM is to provide the "expert information" for the system. The extension advisors provide the heuristic information and make sure that expert information is presented in a manner that will be understood and readily useful to the grower. The knowledge engineer develops the framework for the DSS (ie., the software shell and programming). The role of the growers is to ensure that the DSS suits theirs needs and not the perceived needs by the researchers. The growers evaluate the system to make sure that it is not too technical, easy to use and flexible enough for the user to get the greatest benefit from it. The steering committee meets every three to four months to evaluate progress and suggest any changes. To date this approach has proven very successful (Clarke *et al.*, 1994b).

As stated earlier, the HGCM is aimed at all aspects of greenhouse production. Thus, the user is asked to enter information of their greenhouse structures, growing practices and production tasks. This information is stored in the database and is assessible to the user in tabular and graphical form. For disorder identification, the user can answer questions using a standard couplet key or use pictures. Foreward and backward reasoning processes were used in developing the expert system part of the DSS. The accuracy of the identification module has been tested with growers and has proven quite successful. When disorders can not be accurately diagnosed, the rules for identification are re-examined and modified where necessary.

The major advantages and disadvantages associated with using the HGCM are listed below:

Advantages

1. Information on greenhouse production is present at one place and accessible anytime.
2. User can obtain rapid answers to problems and the solutions are presented as options.
3. Information is presented as text, pictures, graphs and tables.
4. Use of the DSS will improve efficiency of greenhouse production by avoiding conflicting practices or reccommendations and by increasing the efficiency of different production tasks.
5. Forecasting of potential disorder outbreaks and the rapid implementation of prevention strategies such as manipulation of greenhouse environment, nutrient schedules or other practices.
6. The DSS assists the grower in organizing and managing data for all aspects of greenhouse crop production.

Disadvantages

1. HGCM is a new software program to learn.
2. There is no personal contact if a user wants additional information or has more questions on a particular problem.
3. The system must be periodically updated to keep the information current.
4. The user must be prepared to spent time to use the system and enter information into the database.

<u>Prototyping and Field Testing</u>

The HGCM will be field tested in 1996 with both growers and other "experts" in greenhouse production. Approximately six growers with different backgrounds and production operations will evaluate the HGCM with their own operations. Experts will be selected in the different discipline areas to review the information content to ensure that it is accurate and complete. All evaluators will sign a confidentuality agreement between themselves and Agriculture and Agri-Food Canada. Also, all growers are reminded in the written agreement and on the HGCM that any loss or damage of crop or equipment, as a result of using the HGCM, is not the responsibility of Agriculture and Agri-Food Canada. The members of the steering committee will be available to the growers to answer any questions about the use and suggested recommendations made by the HGCM.

From our experiences in developing the HGCM, we found that the most important component is the steering committee which should include all interested parties, especially the targeted main user. Also, people that are involved in the development of the system must be able to devote the required amount of time that is necessary for their part. Development of DSS will take longer than is initially anticipated and you must be flexible to respond to grower suggestions as the system is developed. To date, we have been able to accommodate all suggestions that have been made by the growers on the steering committee. The system must be user-friendly and flexible enough that the user can make changes to their operation and see the results using text descriptions, pictures, graphs or tabular reports.

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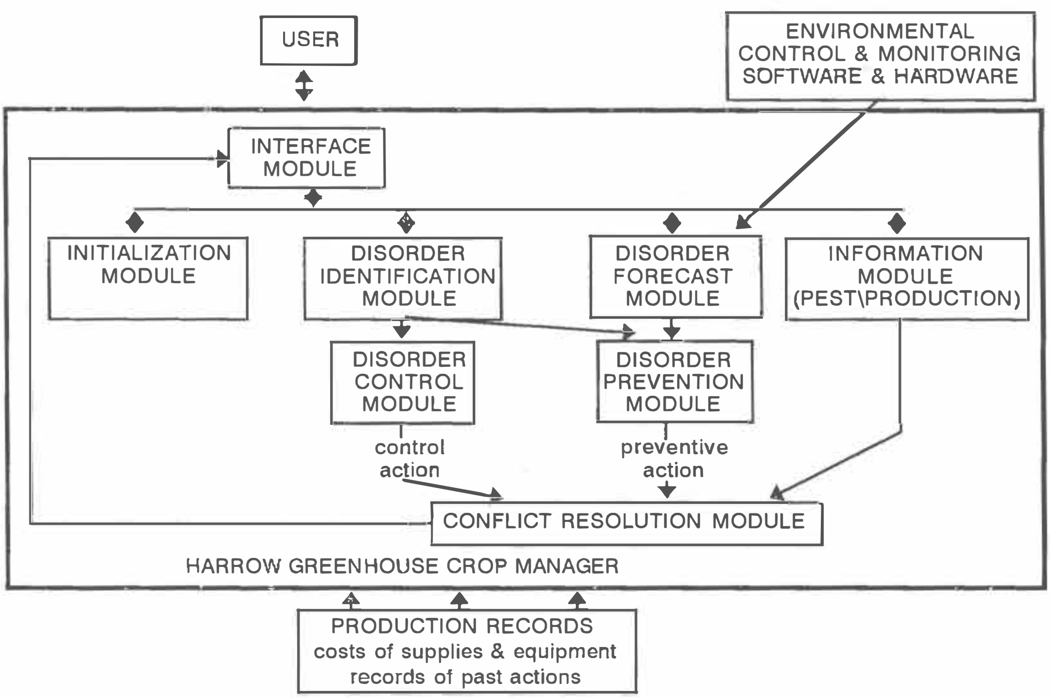

Fig. 1. Schematic overview of the Harrow Greenhouse Crop Manager decision-support system

Different parasitoid introduction schemes determine the success of biological control of *Aphis gossypii* with the parasitoid *Aphidius colemani*

M.J. van Steenis & K.A.M.H. El-Khawass

Research Station for Floriculture and Glasshouse Vegetables, Naaldwijk and Department of Entomology, Agricultural University Wageningen
Present address: Brinkman BV, P.O. Box 2, 2690 AA 's-Gravenzande, The Netherlands

Abstract

Three introduction schemes of the parasitoid *Aphidius colemani*, in which timing and size of the introductions differed, were compared for control of *Aphis gossypii*. The first introduction of each scheme was made one day after aphids had been introduced. An introduction scheme of 100 female *A. colemani* every two weeks suppressed the growth of the aphid population almost immediately. With introduction rates of 50 female parasitoids per week or 25 female parasitoids twice a week, it took two weeks before the aphid population started to decline. With these introduction rates the first offspring of the introduced parasitoids was responsible for successful control.

The results show that natural enemies have to be present in large numbers to obtain sufficient and immediate control. With lower introduction rates not all aphids will be parasitized. As a consequence the aphid population keeps on growing and sufficient control is only obtained when the parasitoid population has build up sufficiently.

In spring control was sufficient with all introduction schemes, but in summer control totally failed. In summer undiscovered colonies will grow much faster than in spring because of the higher temperatures. When the first offspring of the introduced parasitoids emerged these colonies had grown to such a size that parasitism was insufficient to stop aphid population growth.

The total eradication of the aphid population in spring and oscillations in the number of aphids in summer suggest that the interaction between natural enemies and aphids is not stable. Reliable control could be enhanced by ensuring a continuous presence of a sufficient amount of natural enemies.

Introduction

Aphis gossypii Glover (the cotton aphid) (Hom.: Aphididae) is an important pest in glasshouse grown cucumber (van Schelt, 1993). The rapid population growth (van Steenis & El-Khawass, 1995) and its resistance to selective aphicides (Furk & Hines, 1993) make it very difficult to obtain good and long lasting control. Based on population growth rates, host preferences and searching efficiency, *Aphidius colemani* Viereck (Hym.: Braconidae) proved to be the best parasitoid out of several available aphid parasitoids (van Steenis, 1995). However, control is not always reliable.

In this study the effect of three introduction methods on the effectivity of biological control were compared. One extreme consisted of frequent releases of a low number of parasitoids to ensure a continuous presence of parasitoids during the initial phase of biological control. The other extreme consisted of very few introductions with a large number of parasitoids. the experiment was performed once in spring and once in summer.

Materials and methods

Three glasshouses of 101 m^2 with 107 cucumber plants (cv. 'Flamingo') were used. In each glasshouse one leaf (leaf 14 or 15 from below, at a height of approximately 1.5 m) of 14 different plants was infested with five adult aphids. The infestation sites were distributed regularly through the glasshouse. One day later the size of the aphid colonies averaged 42 aphids per leaf and parasitoids were released. Three introduction schemes were used: (1) 25 female parasitoids twice a week, (2) 50 female parasitoids once a week and (3) 100 female parasitoids fortnightly. Parasitoids were introduced at one point in the middle of the glasshouse.

Aphid numbers on the sampling plants were compared with analysis of variance (ANOVA) after a transformation of the data to stabilize variances (Murdie, 1972). Parasitization rates were compared with binomial regression analysis (BRA) in Genstat 5.

The spring experiment started on February 25, 1993 and ended on April 27, 1993. The summer experiment started on June 24, 1993 and ended on October 3, 1993.

Results and discussion

Only when 100 female parasitoids were released (a parasitoid:aphid ratio of 1 to 6) the development of the aphid population in the spring experiment was suppressed immediately (Figure 1). In all colonies the rise to a maximum number of aphids was followed by a rapid decline. When 25 or 50 female parasitoids were introduced it took 15 to 20 days before the aphid population size decreased (Figure 1). The differences among the introduction methods are caused by a lower rate of discovery of aphid colonies with introductions of 25 female parasitoids twice a week and higher initial parasitization rates in colonies found with an introduction of 100 female parasitoids fortnightly ($P<0.05$; BRA) (Figure 2 and 3). Because of the large population growth rate of *A. gossypii* (van Steenis & El-Khawass, 1995) colonies that are not found immediately can grow to such a size that the introduced parasitoids cannot control these colonies anymore. Only when after two weeks many parasitoids emerge from the parasitized aphids in the glasshouse the parasitization rates increase rapidly (Figure 3) and the growth of the aphid population in these colonies can be suppressed too. Parasitization rates were very variable (between 0 and 100%) and no evidence of spatial density dependence was found.

In summer control of *A. gossypii* totally failed. After two weeks the number of aphids started to rise dramatically and only declined after very high aphid levels were reached. A decline phase of several weeks followed until the aphid population started to increase again. One week after the first parasitoid introduction only 40% of the colonies were discovered, a low percentage compared with approximately 80% during the spring experiment ($P<0.05$; BRA). Although control failed, the number of mummies and the parasitization rates in colonies found were higher than in the spring experiment. In contrast with the spring experiment the first glasshouse generation of the parasitoids could not control the further development of the aphid population. Again no evidence of spatial density dependent parasitism was found. The failure might at least be partly caused by the higher temperatures. During the first two weeks the average temperature in spring was 19.8 °C, in the summer experiment the temperature during the first two weeks was on average 24.5 °C. In summer fewer colonies were found during the first week, which might be attributed to the shorter life span of the parasitoids at 25 °C compared to 20 °C (van Steenis, 1993). Additionally, at 25 °C the population growth rate of *A. gossypii* is much larger than at 20 °C (van Steenis & El-Khawass, 1995), whereas the population growth rate of *A. colemani* does not increase as rapidly (van Steenis, 1993). As a consequence in colonies that are not discovered immediately, the aphid population will grow much faster in summer than in spring. These colonies can become a source from which aphid spread into the glasshouse and parasitoids cannot obtain immediate control.

In the spring experiment the parasitoids were able to eliminate the aphids. In the summer experiment two peaks were found in the number of aphids present in the glasshouses. These observations suggest that it is difficult to obtain a low and stable equilibrium population of aphids and parasitoids, when regular parasitoid introductions are used. Efficiently searching natural enemies (like aphid parasitoids) are able to reduce the pest population to low levels but are, according to Murdoch *et al.* (1985), also a cause of instability. As a consequence there is a trade-off between stability and maintenance of a low pest density (Murdoch *et al.*, 1985). Metapopulation dynamics in the field can be stable (van den Bosch *et al.*, 1979), but apparently a glasshouse is too small to result in a stable aphid-parasitoid system (Ramakers & Rabasse, 1995).

It needs to be stressed that the timing of the parasitoid introductions has been extremely well synchronized with the occurrence of aphids. With preventive introductions in commercial glasshouses it is not known when the aphids will enter the glasshouse. Our results suggest that even if the preventive introductions would have been in the right time these introductions are not as reliable as often is suggested. Preventive introductions as long as no aphids are observed in the glasshouse can be useful, but because of the large growth rate of aphid populations many parasitoids have to be introduced frequently. Only when many parasitoids are present a large amount of the aphids will be parasitized soon enough to prevent an increase in aphid numbers. In summer more parasitoids should be introduced than in spring because of the larger growth rate of aphid populations at the high summer temperatures. The results are a strong indictation that the use of an open rearing system in the glasshouse (resulting in a continuous release of a high number of parasitoids) is very usefull tool to get the aphid control going.

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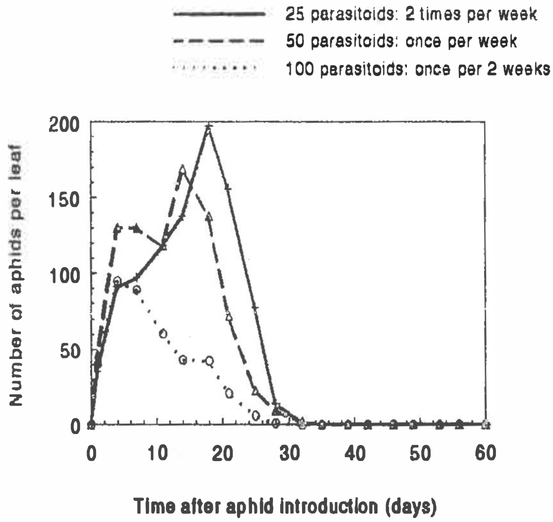

Figure 1
Development of the aphid population on the leaves of introduction during the spring experiment. Three different introduction schemes of *Aphidius colemani* were applied. During the first week the average colony size was significantly higher in the glasshouse where 25 parasitoids were released twice a week ($P<0.05$; LSD after ANOVA). From day 11 to day 25 the number of aphids were significantly lower in the glasshouse where 100 parasitoids were introduced fortnightly ($P<0.05$; ANOVA). After four weeks no significant differences in the average size of an aphid colony could be detected (ANOVA).

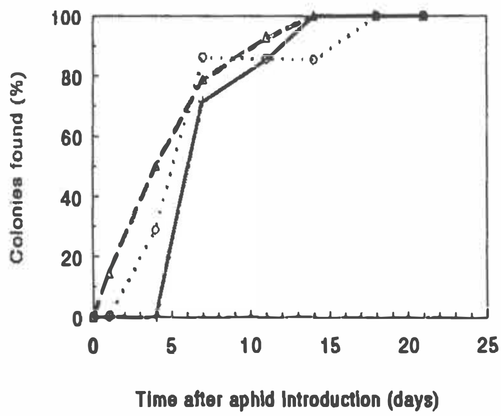

Figure 2
Percentage of colonies found with three introduction schemes of *Aphidius colemani*. It is assumed that a colony was discovered one week before the first mummies appeared.

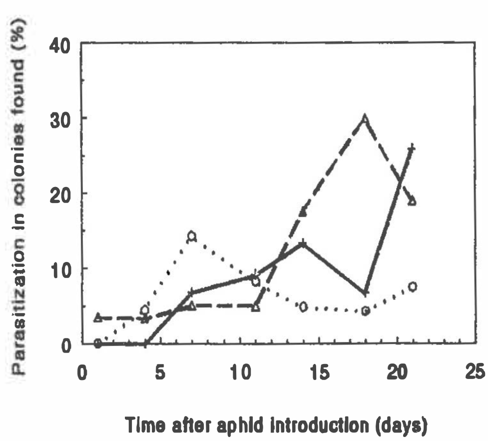

Figure 3
Parasitization rates in colonies found by *Aphidius colemani*. It is assumed that mummified aphids result from parasitization one week earlier. During the first two weeks parasitization rates were significantly higher when 100 parasitoids had been introduced ($P<0.05$; binomial regression analysis).

PERFORMANCE OF *PHYTOSEIULUS PERSIMILIS* AND OTHER BIOLOGICAL CONTROL AGENTS - ON WHAT ARE WE BASING OUR STANDARDS?

M.Y. Steiner[1] and S. Bjørnson[2]
[1] Horticultural Research and Advisory Station, NSW Agriculture, Box 581, Gosford, NSW 2250, Australia
[2] Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada, T6G 2E3

Abstract

The predatory mite *Phytoseiulus persimilis* was obtained from eight sources around the world and evaluated for fecundity, longevity and infection with microbial organisms. Preliminary attempts were made to remove pathogens and reassess performance. Fecundity and longevity increased substantially, the former exceeding or equalling previously published records dating from the days before there were major failures in control of spider mite with commercial supplies. It is suggested that ecological, phylogenetic and behavioural studies dealing with predatory mites and other biological control agents should establish health and fitness of the subject under study before proceeding further, and that quality control guidelines for commercial producers should be re-evaluated.

Introduction

In 1991-92, shipments of the biological control agents *Phytoseiulus persimilis* Athias-Henriot, *Neoseiulus cucumeris* (Oudemans) and *Encarsia formosa* Gahan were obtained from commercial insectaries in Canada, Europe and the United States. There had been major failures in biological control of target pests in cucumber crops in Alberta in the two years previously. A problem with quality of shipments was suspected and demonstrated in a study conducted at the Alberta Environmental Centre, Alberta, Canada. (Steiner 1993a, 1993b). A number of pathogens were also discovered infecting the biological control agents. With a view to determining the extent of the problem in *Phytoseiulus persimilis* and finding or developing a 'clean' source of predators, further studies were conducted at the AEC from 1992-94.

Methods

A single shipment of *Phytoseiulus persimilis* was obtained from each of eight different sources. Three shipments were from Australia (AUl, AU2, AU3), one from New Zealand (NZ) via a commercial outlet in Canada, two from the United Kingdom (UK1, UK2), one from the United States (USA), and one from Israel (ISR). All were obtained from commercial insectaries except NZ, AUl and USA strains which were from research facilities. Shipments were obtained on the following dates: AUl on 27/6/93, AU2 and AU3 on 27/10/93, NZ on 30/6/93, UK1 on 26/10/93, UK2 on 11/12/93, USA on 23/12/92 and ISR on 25/8/93. Colonies were maintained on *Tetranichus urticae* Koch on green beans in screened cages in greenhouse units maintained at approximately 25°C and 18L:6D . Cages were kept isolated from each other over moats of soapy water in quarantine conditions. Fresh beans with spider mites were added weekly and the colony size maintained at approximately 500 individuals as far as possible to prevent overcrowding.

On arrival, a minimum of 20 adult females were smeared individually and Giemsa-stained to detect microorganisms. Some were also submitted for electron microscopy (see Steiner 1993a for details on procedures). A further 20 were placed individually in screened Millipore® dishes with a disc of spider-mite infested green bean leaf on wet irrigation felt. Dishes were checked daily for seven days. Number of eggs were recorded daily and removed. Mites were noted as live or dead or with obvious signs or symptoms of ill-health. Dead predatory mites were smeared, stained and checked for microbial infection. Periodic checks on colony condition were made between runs by smearing and staining 20-40 individuals. Stained slides were checked for rickettsia-like organisms (RLO's), fungi, bacteria, gregarines and microsporidia. Electron microscopy was used to check for these organisms and also for virus. All potential pathogens except gregarines (found in *Tyrophagus putrescentiae* (Schrank)) had previously been found in *P. persimilis* during the earlier study (and some also in *N. cucumeris*, *T. urticae* and *T. putrescentiae*) (Steiner 1993a).

As a result of poor fecundity and longevity exhibited by *P. persimilis* from all sources, an attempt was made to remove microorganisms by treatment with antibiotics. As the food source, the spider mite colony was targeted first. Eggs were removed from infested leaves by screening and dipped in 1:4 formaldehyde solution (8%) for 5 min., followed by three rinses in distilled water. Eggs were filtered using a Buchner funnel and the filter paper with eggs was placed in small leaf cages containing treated bean leaflets. Bean leaflets were pretreated with dips of either distilled water, or three rates of tetracycline hydrochloride (0.5, 1.0, 1.5 mg/mL of water). Once eggs had hatched, bean leaves were replaced with freshly treated ones. Six days post-treatment, 10 adult mites/treatment were smeared, Giemsa-stained and checked for microorganisms. Tetracycline-treated mites appeared larger and were more numerous than those in non-treated units. Only the 1.0 and 1.5 mg/mL rate produced mites apparently free of infection (primarily RLO's), so the 1.5 mg/mL-treated mites were used to start a 'clean' colony.

The source AU3, one of the worst performers, was selected to examine the effect of similar treatment on *P. persimilis* fecundity and longevity. Eggs were collected by filtering through screens under running water. Thirty eggs were placed in each leaf cage unit after treatment and maintained at 25°C. Treatments were T1=5 min. distilled water rinse; T2=as T1+5 min. rinse in 8% formaldehyde; T3=T1+T2+5 min. rinse in 0.5 mg/mL tetracycline hydrochloride; T4=T1+T2+5 min. rinse in 1.0 mg/mL tetracycline hydrochloride; T5=T1+T2+5 min. rinse in 1.5 mg/mL tetracycline hydrochloride. There were three replicates per treatment. 'Clean' spider mites were added as food. On Day 5, the number of live *P. persimilis* in each unit was recorded. Eggs were first noted on Day 6. Adult predators were removed from the units and 20/treatment placed individually in Millipore® dishes to assess fecundity and longevity. Twenty adults were also smeared and stained in each treatment.

Results and discussion

Results of the fecundity and longevity tests on non-treated *P. persimilis* are summarised in Table 1. None gave acceptable levels of either measure of fitness, with fecundity ranging from means of 0.05-1.36 eggs/female/day and longevity from 0.58-4.20 days over a seven day period. Stained slides showed varying levels of infection with microorganisms, particularly RLO's. The USA colony died out before a third run could be carried out. Except for the Australian material, microbial load was low in specimens when first received and tended to increase over time, though this sometimes reversed itself. RLO's (in several cases difficult to distinguish from bacteria) were the most common organisms found, though they were not always present in large numbers in poorly performing mites, and occasionally were numerous in mites that had laid well. Microsporidia were rarely observed in smears, but were numerous in a small number of mites in AU2, AU3, UK1 (Bjørnson *et al.* 1996, in press) and suspected of being present in others. The particular microsporidium in UK1, not previously described, was transovarially transmitted and significantly reduced fecundity to <2 eggs/female/day (S. Bjørnson,unpublished data). Non-occluded virus was found in samples from USA, NZ, UK1, AU1, AU2 and AU3, using electron microscopy. Only a few individuals could be processed by this method so virus may be more commonly present than is supposed. Virus could not be detected in stained smears though large circular crystal formations previously associated with virus in citrus red mite were not uncommon.

The number of adult *P. persimilis* surviving from treated AU3 eggs introduced into leaf

Table 1. Fecundity and longevity of *Phytoseiulus persimilis* from eight sources, 1993-94

Source	Treatment	Date	Mean days live/week (range)	Mean eggs/day/female (range)	n
UK1		16/10/93	3.21 (0-7)	0.45 (0-1.29)	19
		07/11/93	2.45 (0-7)	0.74 (0-1.86)	20
		29/12/93	4.02 (0-7)	1.17 (0-3.43)	19
UK2		29/12/93	2.89 (0-7)	0.98 (0-5.00)	18
		14/01/94	3.82 (0-7)	0.66 (0-3.14)	17
		14/01/94	4.20 (0-7)	1.36 (0-4.57)	15
AU1		16/10/93	1.85 (0-6)	0.16 (0-0.86)	20
		13/12/93	1.88 (0-4)	0.28 (0-0.86)	16
		06/01/94	2.74 (0-7)	0.53 (0-2.71)	19
AU2		07/11/93	1.35 (0-4)	0.23 (0-0.86)	17
		13/12/93	1.89 (0-7)	0.43 (0-1.57)	18
		06/01/94	2.94 (0-7)	0.60 (0-1.86)	18
AU3		07/11/93	1.35 (0-4)	0.19 (0-0.71)	20
		13/12/93	0.88 (0-7)	0.05 (0-0.57)	18
		06/01/94	2.61 (0-7)	0.86 (0-3.71)	18
ISR		31/10/93	1.71 (0-6)	0.22 (0-1.00)	17
		12/11/93	2.35 (0-7)	0.44 (0-3.57)	20
		29/12/93	3.44 (0-7)	0.56 (0-2.57)	18
NZ		31/10/93	2.56 (0-6)	0.41 (0-0.86)	19
		12/11/93	3.00 (0-7)	0.41 (0-2.29)	19
		29/12/93	3.35 (0-7)	0.71 (0-2.57)	16
USA		31/10/93	1.22 (0-7)	0.15 (0-1.29)	18
		12/11/93	0.58 (0-3)	0.07 (0-0.57)	19
AU3[1]	T1	15/03/94	6.75 (5-7)	4.73 (2.57-5.86)	16
	T2	15/03/94	3.75 (0-7)	2.45 (0-5.14)	12
	T3	15/03/94	5.37 (1-7)	3.39 (0.57-5.57)	19
	T4	15/03/94	4.67 (0-7)	3.39 (0-5.71)	18
	T5	15/03/94	5.50 (0-7)	3.40 (0-5.57)	18

[1] Colony established from eggs treated for pathogens

cages was highest for water-treated and formaldehyde-treated eggs, but not significantly different from those treated with tetracycline hydrochloride. Treated mites showed much higher fecundity and longevity than in all previous tests (Table 1). Mean fecundity ranged from 2.45-4.73 eggs/female/day and longevity from 3.75-6.75 days over a seven day period. Reported fecundity in the literature is 2.4-4.0 eggs/female/day. Several mites laid 8 eggs/day. T2 was short on mites due to an error in handling. Surprisingly, water-rinsed mite eggs gave the best results. Stained slides showed a very low level of infection with RLO's, but this was also true of the colony as a whole, which had performed badly two months previously and had a heavy infection of RLO's. The untreated main colony was not assessed for fecundity and longevity in March.

There are several possible explanations for the improved health of the colony. Either frequent transfers succeeded in substantially reducing the general level of infection in the main colony, or eggs are not the main source of horizontal or vertical transmission of pathogens (microsporidia and RLO's have been found in eggs previously (Steiner 1993a)), and/or treatment with a water-rinse is adequate to remove most of the pathogen load. Predatory mites used in the last experiment were young and of uniform age so may have performed better, though mixed age populations gave averages as high as 3.92 eggs/female/day in 1991 (Steiner 1993a, 1993b). Nevertheless, it is clear that when healthy, *P. persimilis* is capable of laying far more eggs/day than present quality control guidelines stipulate (van Lenteren 1993, Anon 1994). These allow for a seasonal test with only 30 individuals and accepts 2 eggs/female/day over a five day period as being acceptable. Clearly diseases or other health problems are in danger of being overlooked. Of perhaps greater concern is that phylogeny, evolutionary theory and predator/prey models are being developed (Janssen and Sabelis 1992, Sabelis and Jansenn 1994, Zhang 1995) on the basis of published fecundity, longevity and other characteristics of predatory mites that may be based on unsound data. Unless *P. persimilis* (or any other biological control agent for that matter) have been established as fit and free of disease, then the foundations of our present assumptions of behaviour etc. are shaky at best and in need of revision.

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INVESTIGATIONS ON THE OCCURRENCE OF AGROMYZID LEAFMINERS AND THEIR NATURAL ENEMIES IN GREENHOUSE CUT GERBERA IN AUSTRIA

M. Stolz
c/o BFL, Institut für Phytomedizin, Spargelfeldstr. 191, A-1226 Vienna

Summary
Since the early nineties the serpent leaf miner *Liriomyza huidobrensis* has become a major pest in vegetable and ornamental greenhouse crops in Europe. During trials in greenhouse cut gerbera in Austria the occurrence of agromyzid leafminers and their parasitoids in either integrated control programs including *Dacnusa sibirica* TELENGA (Braconidae) and *Diglyphus isaea* WALKER (Eulophidae) and in greenhouses with chemical treatment was investigated. Released massreared parasitoids as well as naturally occuring wasps established in the crop and reduced the leafminer infestation satisfactory. The eulophid *D. isaea* was more effective in combination with cyromazine than *D. sibirica*.

Introduction

While the endemic species of agromyzid leafminers in Austria like *Chromatomyia horticola* do not cause damage of economic importance in vegetable and ornamental cultures, infestations with two imported leafminers-species from North America lead to significant reductions in quality as well as in quantity up to total losses of the crop (van der Linden, 1990). The chrysanthemum leaf miner *Liriomyza trifolii* BURGESS was imported with chrysanthemum cuttings to the Netherlands in 1976 (Minkenberg, 1988) and was noticed in Central Europe (Austria, Switzerland) in the mid eighties. *Liriomyza huidobrensis* BLANCHARD, the serpent leaf miner, occurred in the Netherlands the first time in 1989 (van der Linden, 1990) and could be observed in Austria since the early nineties. The imported species of *Liriomyza* show a high increase of population as well as a high resistance to pesticides (Leuprecht, 1991). Additionally, protected stages like the larvae in the leaves and the pupae in the leaf or in the soil make the control of these pests difficult. An effective alternative to the chemical control can be the biological control, releasing parasitic wasps like *D. sibirica* and *D. isaea*. Reduction of leafminer infestations is achieved by parasitization and hostfeeding of the parasitoids.

Methods

Several gerbera greenhouses with either biological control or with chemical treatment were chosen to investigate the population development of *L. huidobrensis* and its natural enemies. Twenty mined leaves of each culture were collected weekly during the whole growing seasons in 1994 and 1995 and were classified according the degree of leaf damage. Leaf samples were kept in the laboratory until the emergence of the leafminers and its parasitoids in order to assess the percentage of parasitization and for determination.

Results

At the start of the trials in April 1994 a moderately high infestation level of the gerbera crop with *L. huidobrensis* at about 50 % of the leaves surface mined, was observed. Massreared *D. sibirica* were released six times in about weekly intervals at an introduction rate of 0,25 parasitoids/m². Additionally, the endemic species *D. isaea* immigrated from surrounding outdoor crops into the gerbera greenhouse (fig. 1a). The parasitoids reduced the leafminer infestation successfully within one month. During the extreme hot summer period of 1994 no infestation was observed on the gerbera plants. However a small population of *L. huidobrensis* as well as of the two parasitoid species remained on weeds (*Cirsium arvense*) within the greenhouse compartement. At the end of September, when first feeding points and small mines were detected, *D. sibirica* was released again. The number of adult leafminers increased rapidly, so that the economic treshold level was exceeded and the gerbera flowers were covered with feeding points. The crop was sprayed with cyromazine, which is considered to be harmless for *D. sibirica* and *D. isaea* (Hassan et al., 1994).
In spring 1995 (fig. 1b) the infestation of gerbera with *L. huidobrensis* in the same greenhouse was only about one third of the level of 1994 and could be suppressed by one release of *D. sibirica* (0,25/m²). *D. isaea* occurred with twice more individuals than in the year before and reduced the endemic *Chromatomyia horticola* which had immigrated into the crop from outdoor weeds. At the beginning of October *L. huidobrensis* could be observed again and *D. sibirica* were released two times followed by *D. isaea* (à 0,05/m²). When the number of the leafminers increased, the crop was treated with cyromazine to avoid the losses of the last year in the flowers, although the number of the parasitoids in the crop also enhanced. *D. isaea* survived this pesticide application in a higher number than *D. sibirica*. In another gerbera greenhouse (1000m², fig. 2) with a six times higher infestation of *L. huidobrensis* than in the first described compartement the leafminer infestation could finally only be reduced by immigrated *D. isaea* although *D. sibirica* had been released six times (1,5 to 0,5/m²) before *D. isaea* occurrred.
In the gerbera greenhouse with weekly applications of pesticides (1100m², fig. 3) *L. huidobrensis* was present in varying densities during the season. Parasitoids were never found except once *Cyrtogaster sp.,* which was surprisingly detected after several applications of broad spectrum insecticides only ten days after a methomyl treatment.

Discussion and conclusions

In the course of the presented trials the occurrence of different leafminer species and their parasitoids on greenhouse cut gerbera was investigated extensively for the first time in Austria. Since the start of the investigations in autumn 1993 only *L. huidobrensis* was detected, whereas no other leafminer species imported from North America could be found. As endemic, polyphagous species *C. horticola* sporadically immigrated from surrounding outdoor weeds into the gerbera greenhouses. While *L. huidobrensis* was present in the crop during the whole year, *C. horticola* was found only during the period of its natural occurrence in the field from May to October. The leafminer parasitoids found most frequently were *D. sibirica* and *D. isaea*, which are endemic in

Figures 1-3: Population development of *Liriomyza huidobrensis* and its natural enemies on greenhouse cut gerbera. Comparison of integrated and chemical control effects

Figure 1a

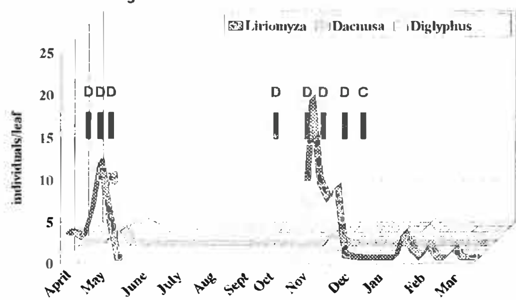


Figure 1b

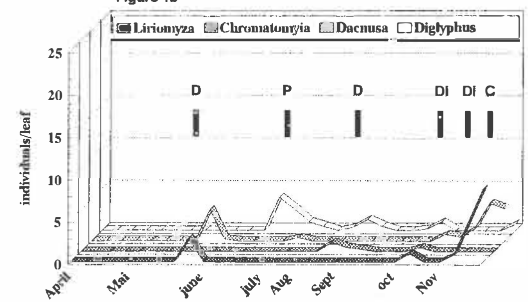


fig. 1+2: cut gerbera cultures (1 and 2) with integrated control of *L. huidobrensis* (fig. 1a: 1994, fig. 1b and 2: 1995)
fig. 3: cut gerbera culture with chemical control of *L. huidobrensis*
D ... release of *Dacnusa sibirica*, Di ... release of *Diglyphus isaea*, C ... cyromazine, P ... various pesticides

Figure 2

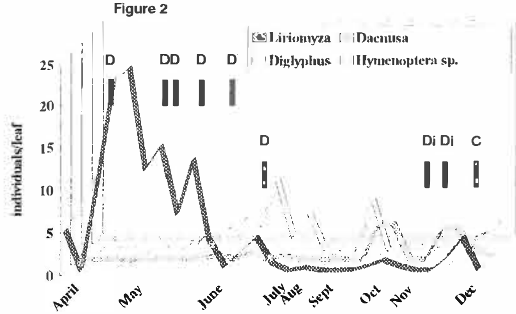
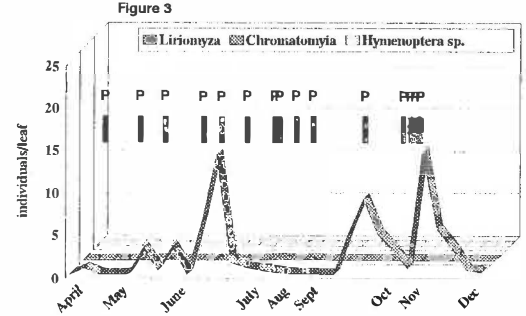


Figure 3



Austria. *D. sibirica* was mainly observed in the gerbera after the release of massreared wasps, in contrast to *D. isaea* which exclusively invaded from the field. To a lesser extent the naturally occuring Chalcidoid *Cyrtogaster sp.* could be reared from gerbera leaf samples. Parasitoids were regularly found in the greenhouses with integrated control, however only once in the greenhouse where chemical treatment was applied. The trial results show that the integrated control of *L. huidobrensis* including only one supporting treatment with a selective insecticide reduced the pest population more effective than non selective chemical treatment with fifteen applications. For biological control monitoring of the feeding points caused by *L. huidobrensis* in order to estimate the correct timing of the beneficial release is especially important, because the first mines can often only be detected after the leaf tissue has been already severely damaged, in contrast to the injury level caused by *L. trifolii* and *C. horticola* at the same time.

In greenhouse cut gerbera parasitic wasps can be released the whole year round because the cultivating temperature always exceeds 10°C. Both *D. sibirica* and *D. isaea* effectively parasitize leafminer instars at temperatures of aproximately 15°C and are able to survive lower temperatures. Larval instars and pupae of *D. isaea* were even found at temperatures of 5°C in the field. As leafminer control within integrated pest management in greenhouse cut gerbera proved to be successful, investigations of the efficacy of biological control measures alone would be of interest in future.

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HAIRINESS OF *GERBERA JAMESONII* LEAVES AND THE WALKING SPEED OF THE PARASITOID *ENCARSIA FORMOSA*

Susanne Sütterlin & Joop van Lenteren

Department of Entomology, Wageningen Agricultural University, P.O. Box 8031, 6700 EH Wageningen, The Netherlands.

Abstract

To characterize the relation between the leaf surface of ten *Gerbera jamesonii* cultivars and the searching behaviour of the parasitoid *Encarsia formosa* on a leaf, the trichome density and -length were described. Both parameters varied among the cultivars. The density varied from 80 to more than 1000 trichomes per cm^2. The walking speed was the tested parameter of the searching behaviour of the parasitoid on the leaf. In spite of the differences in leaf surface structure the walking speed was between 0.2 and 0.3 mm/s on all cultivars and was not significantly different from the speed on tomato. That hairiness in general does hamper the parasitoid females was illustrated by the walking speed on the hairless sweet pepper (0.73 mm/s). Consequences of the results of the searching behaviour of *E. formosa* on *G. jamesonii* cultivars are discussed with respect to other host plants and the possibilities of biological control on this ornamental plant.

Introduction

At present, the use of biological pest control as cornerstone of IPM programs is strongly stimulated by governmental policies. For greenhouse vegetables such programs are now common use (van Lenteren, 1994) and development of such programs for ornamental crops are of high priority (Fransen, 1992). *Gerbera jamesonii* seems to be a good ornamental host plant to start with, because only the flowers are marketed and a certain degree of injury or even whiteflies present on the leaves can be tolerated. A wide range of different cultivars is grown in *G. jamesonii*. Cultivars may vary substantially in leaf size and in leaf surface structure. Insects may profit as well as being hampered from the conditions on the surface (Southwood, 1986). This holds not only for the herbivorous insects, but also for insect parasitoids. The leaf hairiness may influence the walking behaviour of the parasitoid *Encarsia formosa*. Walking of a parasitoid consists of its (i) walking activity, (ii) walking speed and (iii) walking pattern. If *Gerbera* leaf hairiness has an important negative effect on either walking activity (less walking), walking speed (slowing down) or walking pattern (less straightness), it would result in a lower encounter rate of *E. formosa* with its hosts. This affects the biological control of *T. vaporariorum*. The influence of hairiness on the walking activity and -pattern is discussed in detail elsewhere (Sütterlin & van Lenteren, 1993; Sütterlin & van Lenteren, submitted and Sütterlin et al., 1993).

In this article data are presented on the influence of the hairiness of *Gerbera* cultivars on the walking speed of the parasitoid *E. formosa*. In a cucumber cultivar with a hair density that is half as large as that on traditional cultivars, the parasitoids walking speed increased from 0.20 mm/s to almost 0.40 mm/s (van Lenteren et al., in press). It is, therefore, hypothesized that the walking speed of *E. formosa* is highly influenced by plant species or cultivars with differences in the leaf surface.

Material and methods

Plant material.

The *G. jamesonii* cultivars 'Dragon', 'Estelle', 'Fame', 'Irmgard', 'Macho', 'Pacific', 'Parade', 'Party', 'Provence' and 'Tennessee' were used for measuring trichome density and shape. The plants were grown in a glasshouse compartment at a mean temperature of 20 1 °C and a light regime of 16 light / 8 hours dark. *Gerbera* plants had eight full grown leaves and were three to four months old when used in the experiments.

Leaf hair density and length.

The hair density was determined by counting the number of trichomes on the underside of leaf discs with a diameter of 5 mm under a binocular with cold light lamps, at a magnitude of 10 times. For the cultivar 'Fame' we analyzed 50 leaf discs (from base, centre, edge and top of the leaves) of full grown leaves (leaf numbers four and five, counted from the youngest unfolded leaf of the rosette) from five plants. For each of the nine other cultivars 10 leaf discs per plant from two different plants were analysed. Differences between the cultivars were tested with a Kruskal-Wallis test ($\alpha = 0.05$) followed by a multiple comparison test. The length of the trichomes was measured on 10 leaf discs (10 hairs per disc) for every cultivar. Differences in trichome length between cultivars were tested in the above mentioned way.

Parasitoids

Black pupae were weekly obtained on carton cards from 'Koppert Biological Systems'. Cards were places in glass petri dishes of 5 cm diameter. The parasitoids that emerged were provided with a droplet of honey placed on the petri dish. Naive *E. formosa* females, not older than 16 hours were used in the experiments. The females were kept at a temperature of 20, 25 or 30 °C, in anticipation of the experimental conditions.

Walking speed

For a comparison of the walking speed with the behaviour of *E. formosa* on other (vegetable) host plants of *T. vaporariorum*, the experiments at 20 °C were also done on sweet pepper (*Capsicum annuum*, cultivar 'Westlandse-Zoete') and tomato (*Lycopersicon esculentum*, cultivar 'Moneymaker'). To determine the walking speed of the *E. formosa* video recordings were made. The followed procedure is described in detail in Van Roermund & van Lenteren (1995) and Sütterlin & van Lenteren (submitted). Differences in walking speed on the cultivars were tested with Kruskall-Wallis ($\alpha = 0.05$) followed by a multiple comparison test.

Results

1. Leaf hair density, hair length and trichome shape

The number of trichomes per cm^2 per cultivar and their length is given in table 1. A large variation in hair density is seen among the ten tested cultivars: from 80 up to 1041 trichomes per cm^2. Concerning the hair density three significantly different groups of cultivars could be distinguished. All trichome lengths exceeded 0.6 mm, which is the height of *E. formosa*. The hair length varied from one to two mm outstretched. No subdivision in hair length groups was made, distinct groups were not found.

2. Searching behaviour of *E. formosa*

Walking speed

The range of walking speed of *E. formosa* on different *Gerbera* cultivars was small and varied between 0.2 mm/s and 0.3 mm/s at 20 °C (figure 1). A significant difference in walking speed was found only between cultivar 'Tennessee' and cultivars 'Macho' (Kruskal Wallis, $p = 0.01$ and Mann Whitney U-test, $\alpha = 1.79*10^{-3}$ and $p = 0.003$) and 'Estelle' (Kruskal Wallis, $p = 0.01$ and Mann Whitney U-test, $\alpha = 1.79*10^{-3}$ and $p = 0.004$), respectively (figure 1). The mean walking speed on *G. jamesonii* cultivars at 20 °C was 0.25 mm/s *sd* 0.035. Wasps tested on the *Gerbera* cultivar 'Macho', with the lowest leaf hair density, did not have a significantly higher walking speed compared to seven other cultivars. A negative relationship between hair density and walking speed could not be established for *Gerbera* (figure 1 and table 1). On the hairless sweet pepper plants the wasps had a significantly higher walking speed, 0.73 mm/s *sd* 0.33 (Mann Whitney U-test, $p << 0.001$). On tomato the walking speed (0.31 mm/s *sd* 0.16) was the same as on the *Gerbera* cultivars. However, the hair density of tomato is above 1900 trichomes per cm^2 (Hulspas-Jordaan & van Lenteren, 1978) and much higher than found on the *Gerbera* cultivars.

Discussion

The large difference in trichome density (a factor 13) and shape did not reveal a wide range in the walking speed of the *E. formosa* females on the *G. jamesonii* cultivars. For two cucumber cultivars of different hair densities, one cultivar has half the trichomes per cm^2 as the other, Li et al. (1987) report 0.1 mm/s difference in the walking speed of *E. formosa*. That no negative lineair relationship between walking speed and hair density was found on *Gerbera*, is in contrast with cucumber, where hairless, half-haired and 'hairy' cultivars were tested (van Lenteren et al., in press). On the hairless, smooth sweet pepper plant, cultivar 'Westlandse Zoete' a significantly different, much higher walking speed of the wasps was found compared to all *Gerbera* cultivars. The walking speed on sweet pepper (0.73 mm/s) resembles the walking speed of *E. formosa* as measured by van Lenteren et al. (in press) on hairless cucumber (0.65 mm/s). This may illustrate that leaf hairiness in general hampers the parasitoid. The walking speed of females on *Gerbera* at 20 °C, between 0.2 and 0.3 mm/s, is lower than on half-haired cucumber, 0.40 mm/s (van Lenteren et al., in press) or sweet pepper. The walking speed on *Gerbera* is not significantly different from the speed on tomato, 0.3 mm/s, where biological control of the greenhouse whitefly with *E. formosa* is succesfully applied (van Lenteren & Woets, 1988). However, the walking speed of *E. formosa* on tomato (van Roermund & van Lenteren, 1995) is at different temperatures in trend a little higher than on *Gerbera* cultivars.
The leaf hairiness of *Gerbera* cultivars is no complicating factor for the searching behaviour of *E. formosa* on leaves (Sütterlin & van Lenteren, submitted). All the results point in the direction that biological control of *T. vaporariorum* with the parasitoid *E. formosa* should be possible on *Gerbera* on a larger scale.

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Table 1
Number of trichomes per cm^2 and their length (mm) on fullgrown leaves of ten *Gerbera* cultivars. Standard deviation (sd_{n-1}) and *n* are given between brackets.

cultivar	hair density (*sd*; *n*)	hair length (*sd*; *n*)
Macho	80.0a (42.0; 20)	1.2abd (0.4; 10)
Irmgard	100.1a (37.2; 20)	1.9bcd (0.1; 10)
Fame	111.7a (39.4; 20)	1.6bd (0.4; 10)
Provence	122.7a (32.9; 20)	1.5b (0.2; 10)
Pacific	131.1a (25.4; 20)	1.6abcd (0.1; 10)
Dragon	251.4b (59.6; 20)	1.3abd (0.3; 10)
Estelle	251.4b (60.9; 20)	2.0c (0.3; 10)
Parade	338.3b (93.3; 50)	1.8cd (0.2; 10)
Tennessee	363.0b (81.1; 20)	1.0a (0.3; 10)
Party	1041.3c (210; 20)	1.8bcd (0.4; 10)

Kruskal-Wallis test, $p < 0.05$, followed by a distribution-free multiple comparison test. Different letters indicate significant differences in hair density or in hair length between cultivars.

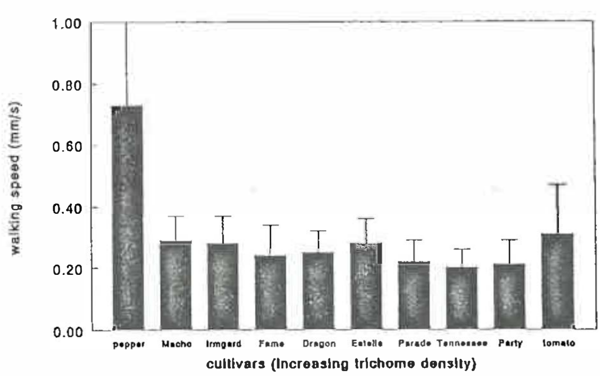

Figure 5
Mean walking speed of *E. formosa* on eight *Gerbera* cultivars, sweet pepper and tomato. The leaf hair density of the plants increases from the left to the right (vertical bars: standard deviations).

Prospects for integration of the defence abilities of the host plant and Phytoseiulus persimilis activity in spider mite control on cucumber.

Anna Tomczyk & Anna Piłko

Department of Applied Entomology, Warsaw Agricultural University,
Nowoursynowska 166, 02 - 787 , Warsaw , Poland

Abstract

The research was carried out on 3 cultivars of glasshouse cucumbers (Corona, Farbio and Picobello), comparing the development of T. urticae populations : non-controlled and biologically controlled with Ph. persimilis, as well as the growth and yield of plants infested by those populations. Cv. Farbio showed the lowest susceptibility to spider mite. Over 6 weeks, the predator reduced pest population on all tested cultivars by approx. 40 % . At the beginning of infestation the non-protected plants showed more intensive growth by 10 - 20 % than those biologically protected. When the pest population expanded to 200 - 400 specimens per leaf, heavy injures inhibited the growth of non-protected plants - most distinctly in cv Picobello and least visibly in cv Farbio. The highest yield losses were recorded for cv Corona.

Introduction

The knowledge of interaction between pest-resistant cultivars and parasitoids/predators of pest is of significant importance for integrated crop protection. Physical, physiological and chemical properties of plants have an effect on pest and their natural enemies. For example, glandular trichomes on tomato stems affect both spider mites and their predator, Ph. persimilis (van Haren et al. 1987). High content of allelocompounds in resistant plants may have a negative affection on beneficial arthropods. Also, physiological and biochemical changes caused in plants by pest can affect their natural enemies (Boethel & Eikenbary 1986). In many cases a positive interaction between the plant resistance and biological pest control was observed (Starks et al. 1972, Myint et al. 1986, Isenhour & Wiseman 1987). The research on the harmfulness of spider mite to various host plant revealed that their insubstantial populations could stimulate the photosynthesis, growth and yielding of plants (van de Vrie et al. 1972, Tomczyk 1989).
Low density populations of spider mites on plants of a moderate resistance can be sustained due to biological control. A perfect interaction between the plan resistance and biological control should bring the reduction of a pest population to the level which would provide the efficiency of plant defence mechanisms. While studying the harmfulness of spider mite to glasshouse cucumbers, it appeared that many cultivars shoved the ability of compensation or over-compensation of injures caused by spider mites populations of low density (Tomczyk 1989). Thus, the research on the growth and yield of cucumber infested by biologically controlled populations of spider mites seemed to be worth-while.

Materials and methods

The research was carried out in two separate glasshouse chambers on 3 cucumber cultivars : Corona, Farbio, Picobello, grown in rings with garden peat. Sixteen plants of each cultivar (8 plants per chamber) were used for experiment. Five females of T. urticae per leaf were deposited on all tested plants (at the stage of 4 leaves). In one chamber the spider mite populations were controlled with Ph. persimilis, by performing 4 introductions at weekly intervals. In the other chamber the pest was not controlled. The first introduction of the predator was conducted 2 weeks after the initial infestation by spider mite, by depositing 10 specimens of Ph. persimilis per plant. Over two month period the number of spider mites had been repeatedly recorded on all tested plants. At the same time, the young extension growth of shoots was measured, damage index (LDI)was determined according to Hussey and Paar (1963), and also fruits were counted and weighed. Each plant was considered as a separate replication.

Results and discussion

Comparison of the development of spider mite populations on non-protected and biologically protected plants of tested cultivars is presented in Fig. 1 . In the first month of infestation the pest populations had been developing very slowly in all cases. After that time, the populations rapidly grew in numbers on non-protected plants of cvs Corona and Picobello, while on those with predator the number of spider mites was apparently lower . Development of the pest populations on non-protected plants of cv Farbio was slower as compared to the other cultivars. However, the effect of Ph. persimilis on this cultivar appeared two weeks later than in case of cvs Corona and Picobello. It could have be associated with cucurbitacins present in the infested leaves of cv Farbio (Tomczyk, data unpublished) .

The results regarding the growth rate, degree of damage and yield of cucumber plants infested by biologically controlled and non-controlled populations of spider mites, are presented in Tab. 1. and Fig.2.

It was found that in the period of low rate of pest population increase (5 - 45 specimens per leaf) all non-protected plants showed a growth rate higher by 10 - 20 % as compared to those protected by Ph. persimilis and less infested by spider mites. At that time, the degree of damage in protected plants was much lower than it was found in those without the predators . It means that injuries caused by spider mites inducted in plants the processes the growth rate. The length of the extension growth was initially directly proportional to the degree of damage. However, further increase of the latter parameter strongly inhibited the extension growth in non-protected plants as compared to those with the predator. The lowest rate of the growth was recorded in heavily damaged, non-protected plants of cv Picobello. The smallest difference in the same parameter between protected and non-protected plants were found in cv Farbio, which also showed the lowest infestation rate.

In the case of cv Farbio, the yield produced by the plants of both experimental groups showed no significant differences (Fig. 2).However, pronounced yield losses were recorded for non-protected plants of cv Corona. There was no large differences in the yield obtained from plants of both tested groups in case of cv Picobello - probably due to the strong stimulation of the growth and yielding in the initial period of pest feeding.

The presented results indicate large possibilities of damage compensation, even in cucumber cultivars susceptible to spider mites, as already reported (Tomczyk 1989). The use of Ph. persimilis for keeping spider mites populations at a level releasing plant stimulation processes, seems to be perspective. However, establishment of adequate proportions between population of spider mites and predators is necessary to achieve this target and it requires further intensive research.

Table 1 : Growth intensity and development of injury on cucumber infested by T. urticae.
LDI - Leaf Damage Index . I - from 26. 05 to 24. 06. II - From 24. 06 to 14. 07
C - plants controled by Ph. persimilis. NC - plants not controlled. * - on last day of the interval.

Cultivar	plant	date	mite per leaf *	+/-SE	increase in shoot length [cm]	% NC/C	LDI *	+/- SE
CORONA	C	**0**	5		0		0	
		I	29	2.43	104		1.0	0.05
		II	218	18.1	74		2.5	0.05
	NC	**0**	5		0		0	
		I	42	5.41	115	111	1.7	0.12
		II	416	36.1	49	66	3.4	0.08
FARBIO	C	**0**	5		0		0	
		I	19	1.20	112		0.7	0.04
		II	157	17.1	54		1.6	0.08
	NC	**0**	5		0		0	
		I	35	9.73	123	110	1.0	0.02
		II	267	21.4	43	80	2.6	0.07
PICOBELLO	C	**0**	5		0		0	
		I	38	4.01	102		1.2	0.08
		II	285	17.4	83		2.3	0.12
	NC	**0**	5		0		0	
		I	45	5.26	122	120	1.9	0.06
		II	483	14.8	20	24	3.5	0.09

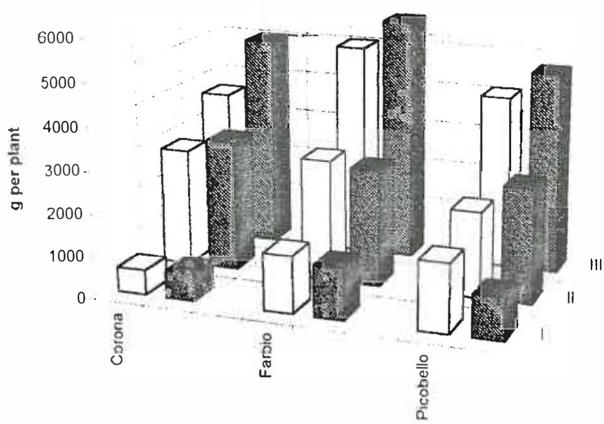

FIG. 2. Yield of cucumber plants infested by controlled and not controlled T. urticae populations
I - first week (mites population to 50 per leaf)
II - next 4 weeks (mites population to 460 per leaf)
III - total (harvested during 8 weeks)

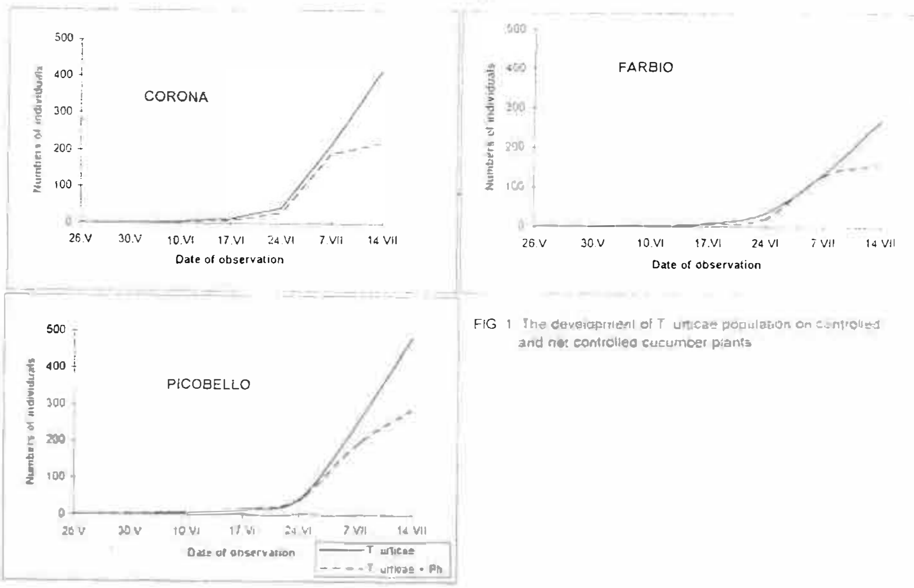

FIG 1 The development of T. urticae population on controlled and not controlled cucumber plants

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INFLUENCE OF TEMPERATURE ON THE DEVELOPMENT TIME AND ADULT ACTIVITY OF *ORIUS LAEVIGATUS*

Maria Grazia TOMMASINI, Massimo BENUZZI
Biolab - via Masiera I, 1191 - 47020 Cesena (FO) (Italy)

SUMMARY

An investigation concerning some biological parameters of a southern Italian strain of *Orius laevigatus* has been conducted at different temperature regimes: three constant temperatures (14°C, 22°C and 30°C), and four fluctuating thermoperiods (23°C (13 hr)/8°C (11 hr); 29°C (9 hr)/5°C (15 hr); 30°C (12 hr)/8°C (12 hr); 31°C (13 hr)/2°C (11 hr)), resembling the climatic conditions of late winter-early spring in unheated plastic tunnels in the Mediterranean area. Embryonic mortality, development time, adult emergence, sex-ratio, pre-oviposition, fecundity after 14 and 25 days and longevity (for a period of 25 days from adults emergence) were recorded. *O. laevigatus* was able to survive and reproduce at all the regimes and at least 50% of the females laid eggs. However, at 14°C constant the predator showed a very slow development time and only few females laid a very low number of eggs. The best performances were observed at 22°C and 30°C. Among the thermoperiods only slight differences were recorded, in particular the thermoperiod 29/5°C (mean 14°C) induced the lowest fecundity on the females, as well as the longest development time.

INTRODUCTION

Since the occurrence of *Frankliniella occidentalis* (Perg.) in Italy (Rampinini, 1987), *Orius laevigatus* (Fieber) was tested for being used as a control agent for *F. occidentalis*. The thrips problem is very serious on different crops especially on strawberry, where nowadays in Italy there is no suitable pesticide allowed for such crop, which combines effectiveness and does not cause any residue problem. For these reasons biocontrol releasing *O. laevigatus,* is constantly increasing as well as growers' interest (Benuzzi & Antoniacci, 1995). Little information is available about the biology of the predator, in the particular temperature situation typical of the protected crops in the Mediterranean Basin during late winter-early spring (Alauzet *et al.*, 1994; Aprel & Aprel, 1995), when *O. laevigatus* have to be released. Therefore the need of evaluating some biological parameters under fluctuating temperature regimes led us to set up the following experiment.

MATERIALS AND METHODS

A southern Italy strain of *O. laevigatus* was reared at seven temperature regimes (four thermoperiods and three constant temperatures), from eggs to the 25th day since the females emerged. The four thermoperiod regimes were chosen because similar to the thermic conditions recorded in unheated plastic tunnels in southern Italy during 1994 (Tab. 1). The experiment was conducted in climatic incubators, computer controlled temperature and RH = 70±10%. At the beginning of the experiment, more than 800 eggs laid on bean pods during 12 hours, were isolated in Plexiglas cylinders (diameter 9 cm and 9 cm high) covered with cotton gauze, for each different temperature regime. Nymphs were fed *ad libitum* with *Ephestia kuehniella* (Zell.) frozen eggs glued on cardboard with Arabic gum; new preys were supplied every week. Twice a day, the eggs were checked to determine the embryonic period, and the nymphs development. The eggs were kept for a period of four days waiting for the nymphs to emerge; then the hatched eggs were counted to define the embryonic mortality. The newly emerged adults were checked to determine the sex-ratio and left together for 3 days to allow mating. After that pairs were isolated in smaller Plexiglas cylinders (diameter 4 cm and 4 cm high) with a piece of pod bean and *E. kuehniella* eggs as prey. Finally for a 22 day period, three times per week, every pod bean was replaced with a fresh one and the eggs laid counted; once per week new preys were supplied. Dead males were replaced regularly. At 30°C constant the adults were isolated already 24 hours after emergence, to avoid the risk of early oviposition, because at this temperature the biological cycle is fast.

Tab. 1 - Environmental conditions set up in the experiment and reference to the period of the year in which similar conditions can be observed into a unheated plastic tunnel in the Mediterranean area.

Temperature regimes	Photoperiods	Hypothetical period of the year
29±1°C/9 hr - 5±1°C/15 hr	12L:12D	February-March
23±1°C/13 hr - 8±1°C/11 hr	12L:12D	February-March
30±1°C/12 hr - 8±1°C/12 hr	12L:12D	March-April
31±1°C/13 hr - 2±1°C/11 hr	12L:12D	March-April
14°C constant	12L:12D	-
22°C constant	16L:8D	-
30°C constant	16L:8D	-

RESULTS

In table 2 the results of the hatching percentage, egg and nymphal development time, as well as the percentage of adult emergence at different temperature regimes are summarised. At all regimes *O. laevigatus* was able to develop, even if with an high embryonic and post-embryonic mortality were recorded (χ^2 test, P<0.001). The shortest development time was recorded at 30°C constant.

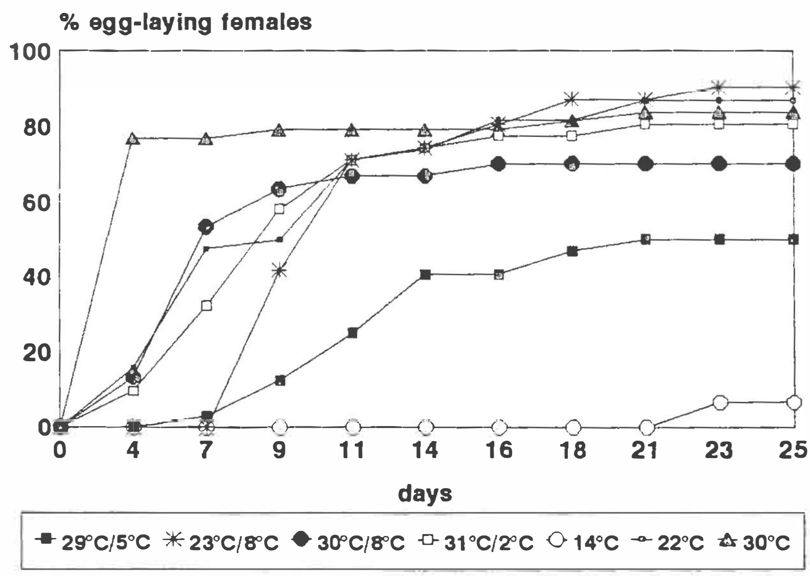
Tab. 2 - Development time, emergence and sex-ratio of *Orius laevigatus* reared at several temperature regimes and 12 hours photophase (regimes at 22 and 30°C constant were combined both at photoperiod 16L:8D). Different letters in the same column indicate significant differences, ANOVA and Tukey test (P < 0.05) (means±SE).

Temperature regimes (°C x hours)	Average Temperature (°C)	N. eggs	Egg hatching (%)	Egg development (days)	Nymphal development (days)	Total development (days)	Adult emergence (%)
14 (24 hr)	14	1101	36.7	15.8 ± 0.12 f	59.4 ± 0.61 f	75.3 ± 0.62 e	6.2
23 (13 hr)/ 8 (11 hr)	16,7	826	64.8	8.1 ± 0.15 e	23.9 ± 0.42 d	31.9 ± 0.44 c	46.6
29 (9 hr)/ 5 (15 hr)	14	1206	59.6	6.2 ± 0.09 d	28.4 ± 0.39 e	34.6 ± 0.35 d	48.3
30 (12 hr)/ 8 (12 hr)	19	1194	71.5	4.8 ± 0.26 b	21.0 ± 0.40 c	25.8 ± 0.48 c	39.3
31 (13 hr)/ 2 (11 hr)	17.7	1007	61.0	5.7 ± 0.20 d	21.5 ± 0.53 c	27.2 ± 0.53 c	45.7
22 (24 hr)	22	1248	66.1	5.3 ± 0.02 c	15.4 ± 0.09 b	20.7 ± 0.09 b	47.8
30 (24 hr)	30	1328	68.0	2.9 ± 0.02 a	10.4 ± 0.15 a	13.4 ± 0.14 a	14.3

Tab. 3 - Pre-oviposition, fecundity and longevity of *Orius laevigatus* within 25 days after adult emergence, rearing the predators at several temperature regimes and 12 hours photophase per day (regimes at 22 and 30°C constant were combined both at photoperiod 16L:8D). Different letters in the same column indicate significant differences, ANOVA and Tukey test (P < 0.05) (means ± SD).

Temperature regimes (°C x hour)	Average Temperature (°C)	N. pairs	Pre-oviposition (days)	N. eggs/female within 14 days from emergence	N. eggs/female within 25 days from emergence	Egg-laying females (%)	Survival females (%)	Longevity within 25 days from emergence (days)
14 (24 hr)	14	25	23.0 ± 1.9b	0 ± 0 a	0.1 ± 0.4 a	30.0	66.7	20.7 ± 1.3 b
23 (13 hr)/ 8 (11 hr)	16,7	31	9.8 ± 3.6 a	12.1 ± 11.3 ab	46.5 ± 26.0 b	90.3	100	25.0 ± 0.0 c
29 (9 hr)/ 5 (15 hr)	14	32	9.9 ± 3.6 a	2.7 ± 4.4 a	12.8 ± 17.6 a	50.0	50	21.2 ± 1.0 b
30 (12 hr)/ 8 (12 hr)	19	30	4.5 ± 2.9 a	23.4 ± 21.5 bc	48.5 ± 42.1 b	71.0	40	22.1 ± 0.7 bc
31 (13 hr)/ 2 (11 hr)	17.7	31	6.6 ± 3.7 a	16.9 ± 17.5 abc	46.2 ± 38.4 b	78.1	80.6	22.9 ± 0.9 bc
22 (24 hr)	22	33	8.9 ± 8.4 a	33.4 ± 30.5 c	83.2 ± 53.9 c	94.6	92.1	24.1 ± 0.5 bc
30 (24 hr)	30	41	2.9 ± 6.1 a	61.9 ± 49.3 d	75.2 ± 67.1 bc	80.4	21.7	15.3 ± 1.1 a

Fig. 1 - Percentage of egg-laying females age-dependent of *Orius laevigatus* reared at different temperature regimes. The photoperiod was set up at 12L:12D apart from the regimes at 22 and 30°C constant, for which the photoperiod was set up at 16L:8D.



Among the thermoperiods, no differences were recorded in the total development time at 23°C/8°C, 31°C/2°C and 30°C/8°C, while the longest cycle was recorded at 29°C/5°C. Comparing all the temperature regimes, the longest development time was recorded at 14°C. The difference found in the development time between the constant regime at 14°C and the thermoperiod 29°C/5°C (mean 14°C) was significative; in fact the nymphs reared at 14°C constant spent twice the time than the other to complete the cycle. No differences were recorded in the sex-ratio among the regimes. In average the percentage of emerged females was of 49.4%, so males and females were considered together for the development time. In table 3 the results concerning the parameters of the adults are shown. The pre-oviposition period was rather similar in all the regimes even if in a wide range, apart from 14°C constant. The highest oviposition was recorded at 22°C constant. At all the regimes apart from 14°C constant and 29°C/5°C, the percentage of egg-laying females was rather high and the predators showed to be able to reproduce also in such environmental conditions (χ^2 test, $P<0.05$). Figure 1 shows the trend of the percentage of egg-laying females age-dependent during the experiment. Apart from 30°C, slight differences in the females longevity among the different temperature regimes were observed, thus thermoperiods do not seem to influence strongly the longevity, at least for the first 25 days of the adult's life. Differences in the percentage of females which survived at the end of the experiment were found (χ^2 test, $P<0.05$).

DISCUSSION

The results obtained show that the predators are able to survive and reproduce at almost all the temperature regimes, although a high immature mortality was recorded. These data confirm the possibility of releasing *O. laevigatus* on strawberry in February-March in the Mediterranean Basin. Moreover, the results obtained allow us to predict, in different environmental conditions (four fluctuating temperature regimes tested), how long it is necessary to wait before starting to monitor *O. laevigatus* after its release on the crop in order to estimate its establishment and reproduction. No induction of diapause was observed at any thermoperiod, even if they were combined with short daylength, and as it is commonly known, low temperature and short daylength can influence the induction in diapause of many species of insects, mainly when cryophase corresponds to scotophase (Beck, 1977). However, the adults reared at 14°C constant and 29°C/5°C seem to show at least a quiescence or a facultative diapause, because only the 30% of the females laid eggs during 25 days, as Tommasini & Nicoli supposed (1995). These data appear to confirm the pre-oviposition threshold temperature of this species which was calculated at 14.2°C (Tommasini, unpublished data).

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EVALUATION OF *ORIUS* SPP. AS BIOLOGICAL CONTROL AGENTS OF THRIPS PESTS. FURTHER EXPERIMENTS ON THE EXISTENCE OF DIAPAUSE IN *ORIUS LAEVIGATUS*

Maria Grazia TOMMASINI*, Giorgio NICOLI**
* Biolab, Centrale Ortofrutticola, via Masiera Prima 1191, 47020 Cesena, Italy
** Istituto di Entomologia "G.Grandi", Università, via Filippo Re 6, 40126 Bologna, Italy

Summary
Photoperiodical response of *Orius laevigatus* (Fieber) was investigated in the laboratory using two strains: strain N collected in northern Italy (ca. 44° N latitude) and strain S collected in Southern Italy (ca. 37° N latitude). Predators were tested from egg to day 29 of adult life at 18±1°C, RH=75±10% and five photoperiods between 11L:13D and 13L:11D (exposure 1) and then for 24 days at 26±1°C and 16L:8D (exposure 2). All photoperiods induced low fecundity during exposure 1 (although the number of egg-laying females increased constantly) and, when switched to exposure 2, more than 90% of females of each group rapidly started to lay eggs, indicating that most predators were in quiescence, or that eventual diapause, if any, must be weak. In addition, wild females were collected in autumn (in the same areas of origin of strains S and N) and kept in a meteorological cabin placed in open air, being monthly isolated in the laboratory (26±1°C; 16L:8D) to check the onset of oviposition up to 3 weeks. The very high oviposition propensity of Southern-Italian females confirmed that they can overwinter in quiescence, while only a portion of Northern-Italian females laid eggs in October-December, indicating that diapause may exist for part of this population.

Introduction
In a large part of the Mediterranean basin *Frankliniella occidentalis* (Perg.) (Thysanoptera Thripidae) remains active in winter (Del Bene and Gargani, 1989) and non-diapausing predators are needed for seasonal inoculative releases in the short-daylength season. Among the *Orius* spp. candidates for biological control, photoperiod induces reproductive diapause in *O.insidiosus* (Say) (Kingsley and Harrington, 1982; Ruberson *et al.*, 1991; van den Meiracker, 1994) and *O.tristicolor* (White) (Gillespie and Quiring, 1993; van den Meiracker, 1994), as well as in *O.majusculus* (Reuter) (van den Meiracker, 1994). No diapause was recorded in *O.albidipennis* (Reuter) (van den Meiracker, 1994) and another palearctic species, *O.laevigatus* (Fieber), overwinters as adult (Péricart, 1972), but the existence of diapause has not yet been proven. Tommasini and Nicoli (in press) carried out initial experiments on the photoperiodical response of *O.laevigatus* using strain N collected in Northern Italy (Po valley; ca. 44° N latitude) and strain S collected in Southern Italy (Sicily, ca. 37° N latitude). Five photoperiods (between 16L:8D and 8L:16D) were tested and the longest developmental times were recorded at 12L:12D for both strains and 16L:8D for strain S, and the shortest ones at 8L:16D for both strains and 16L:8D for strain N. In strain N, 12L:12D induced a reduction in oviposition compared mainly to 16L:8D. Strain S showed slight differences in oviposition related to photoperiod, appearing less sensitive than strain N. Although the low percentages of fertile females in strain S (at all daylengths) and strain N (at short and intermediate daylengths) appeared to indicate a high incidence of diapause, the lack of a photoperiodical response in oviposition mainly in strain S induced us to investigate further the photoperiods around 12L:12D as well as the egg-laying propensity of females collected in nature in autumn.

Materials and methods
Photoperiodical response. The same *O.laevigatus* strains previously tested by Tommasini and Nicoli (in press) were used (ca. 20 generations in mass-rearing). Predators were fed *ad libitum* with *Ephestia kuehniella* (Zell.) frozen eggs glued on cardboard and water was supplied by

wet cotton. The photoperiodical response was tested at 18±1°C, ca. 1,800 lx and RH=75±10%. Bean pods (*Phaseolus vulgaris* L.) with 0-6 hour-old eggs of *O.laevigatus* (n>500) were put into incubators set at the photoperiods 11:13; 11.5:12.5; 12:12; 12.5:11.5; 13:11 (L:D). After hatching, groups of nymphs were reared in transparent cylindrical Plexiglas cages (9 cm high and 9 cm in diameter) covered with cotton gauze. The newly-emerged adults were kept in groups for 4 days for mating; then pairs (n=44 to 50) were isolated in similar cages (4 cm high and 4 cm in diameter) with a piece of bean pod for oviposition. Pairs were maintained at the described conditions until day 29 of adult life (exposure 1) and then moved to another climatic chamber at 26±1°C; RH=75±10% and 16L:8D for 24 days (exposure 2). Survival and oviposition were checked three times a week and dead males were replaced.
Oviposition propensity of overwintering females. Wild populations of *O.laevigatus* were collected in autumn in Sicily (August-November 1994) and in the Po valley (August-October 1994) in the same areas as strains S and N. Adults were phenotypically identified and maintained in glass jars in a meteorological cabin placed in open air in Cesena, Northern Italy, feeding on *E.kuehniella* frozen eggs and with bean pods for oviposition. From August 1994 to February 1995 some females (n=9 to 62) were monthly isolated in cylindrical cages (identical to those of the previous experiment) and placed in a climatic chamber (26±1°C; RH=75±10%; 16L:8D). The onset of oviposition was recorded three times a week up to 3 weeks.

Results

Photoperiodical response. Table 1 reports the pre-imaginal developmental times of both strains of *O.laevigatus* exposed to different photoperiods. No differences were found in the sex-ratio of emerged adults (χ^2 test), so both sexes were considered together. No differences were recorded between the two strains when reared for the same photoperiod (ANOVA), and both strains showed the longest developmental times at 11.5L:12.5D; 12L:12D and 13L:11D.
During exposure 1, fecundity showed differences related to photoperiod as well as the interaction of both photoperiods and strains (ANOVA, P<0.01): strain N showed no differences in the number of eggs laid per female related to photoperiod, while strain S showed a lower oviposition at photoperiods 11.5L:12.5D and 12L:12D compared to 12.5L:11.5D (fig.1). A covariance analysis was carried out the fecundity during exposure 1 being taken as covariate: significant differences were recorded between strains and their interaction with the photoperiod (ANCOVA, P<0.05), but no difference was found among photoperiods (fig.1). The optimal climatic conditions (exposure 2) induced a high oviposition in all groups of females, with no differences in total fecundity (exposures 1+2) related to the strain or to the previous exposure (ANOVA; P<0.05). The percentage of egg-laying females increased progressively during exposure 1 at all photoperiods and, at the last day of exposure 1, strain S was higher than strain N at 11L:13D, 12.5L:11.5D and 13L:11D (χ^2 test; P<0.001), but no differences were recorded in the percentages of fertile females at the end of exposure 2 (χ^2 test) (fig. 2).

Table 1. Pre-imaginal development time (days±SE) of two strains of *Orius laevigatus* reared at 18°C and five photoperiods (ANOVA and Tukey test; P<0.05).

Strain	11L:13D	11.5L:12.5D	12L:12D	12.5L:11.5D	13L:11D
N	34.5±0.7 ab	39.5±0.7 c	36.5±0.7 c	32.0±2.6 a	35.7±1.5 bc
S	34.0±1.4 ab	39.5±0.7 c	39.5±0.7 c	33.5±0.7 a	38.0±0.8 bc

Oviposition propensity of overwintering females. Adult females collected in nature and kept in a meteorological cabin continued to lay eggs up to the mid-November. When placed under optimal conditions, high percentages of egg-laying females were attained within a few days after isolation: only in November strain N did not exceed 50% within 21 days (tab. 2).

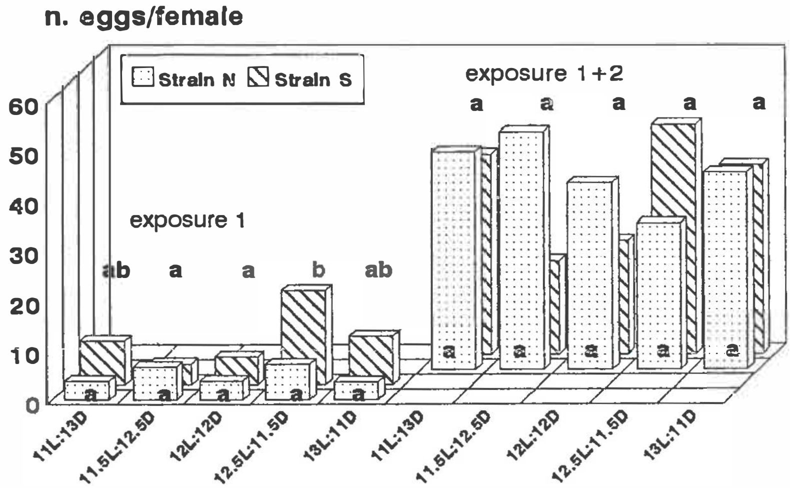

Fig.1: Oviposition of two strains of *Orius laevigatus* reared for 29 days at 18°C and various photoperiods (exposure 1) and for 24 days at 26°C and 16L:8D (exposure 2).

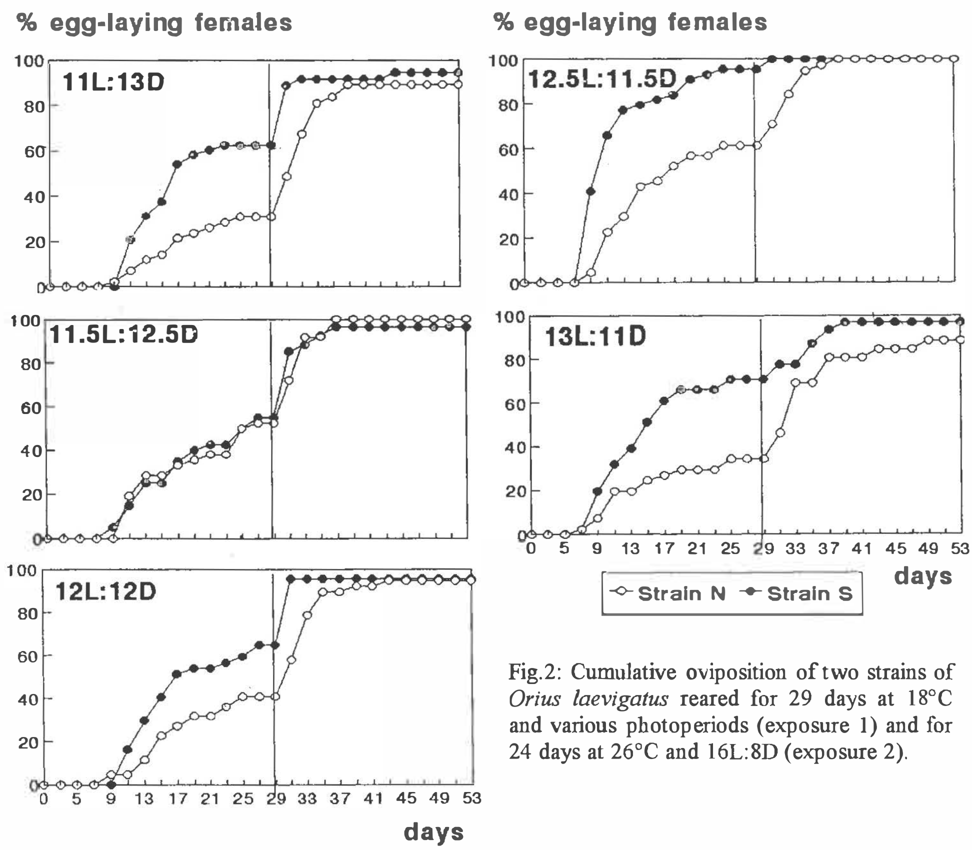

Fig.2: Cumulative oviposition of two strains of *Orius laevigatus* reared for 29 days at 18°C and various photoperiods (exposure 1) and for 24 days at 26°C and 16L:8D (exposure 2).

Table 2. Cumulative oviposition and mortality (%) of *Orius laevigatus* females collected in nature and checked monthly in the laboratory at optimal conditions.

Area of Collection	Northern Italy (Po valley)					Southern Italy (Sicily)				
	n. females	day 3	day 7	day 12*	mortality (21 days)	n. females	day 3	day 7	day 12*	mortality (21 days)
August	9	77.8	77.8	77.8	0	20	100	100	100	0
September	11	100	100	100	0	-	-	-	-	-
October	20	45.0	60.0	70.0	25.0	39	87.2	89.7	89.7	10.3
November	38	2.6	39.5	47.4	52.6	33	42.4	72.7	78.8	15.2
December	18	16.7	55.6	61.1	38.9	46	41.3	82.6	84.8	6.5
January	13	38.5	84.6	100	0	55	58.2	89.1	90.9	9.1
February	-	-	-	-	-	62	80.6	100	100	0

* no females started to lay eggs after day 12

Discussion

The results obtained complete the findings of the previous experiments on the photoperiodical response of *O. laevigatus*, particularly around the hypothetical critical photoperiod 12L:12D (Tommasini and Nicoli, in press). Although developmental times at 18°C differed among photoperiods, no consistent trend was visible and unintended minor deviations in temperature may partially explain these differences. At 18°C, for all the photoperiods tested, the egg-laying activity was very low, as already recorded in the initial experiments (Tommasini and Nicoli, in press), although the extremely low oviposition of strain N at 12L:12D was not confirmed in the present study. When temperature and photoperiod switched to optimal conditions (exposure 2), more than 90% of females of each group rapidly started to lay eggs, indicating that most predators were in quiescence, or that eventual diapause, if any (particularly in strain N), must be weak. The high egg-laying propensity of Southern-Italian females of *O. laevigatus* collected in nature confirmed that many of them can overwinter in quiescence; vice versa, the portion of Northern-Italian females laying no eggs in October-December indicates that diapause may exist for at least a part of this population.

These findings suggest that Southern strains of *O. laevigatus* can be released to control thrips during the short-daylength period, and that they can be profitably used during summer too, as proven by the wide distribution of the species in the warmest areas of the Mediterranean basin.

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BIOLOGY AND MANAGEMENT OF SHORE FLIES (*Scatella stagnalis*) IN A CUCUMBER SEEDLING CROP GROWN IN ROCKWOOL

Irene Vänninen and Heini Koskula
Agricultural Research Centre, Institute of Plant Protection
FIN-31600 Jokioinen, Finland

Abstract: Biological, mechanical, cultural and chemical methods were combined to reduce shore fly (*Scatella stagnalis*) populations in a cucumber seedling crop during the 2.5 months in the summer when the population increase of the flies was at its highest. *Paecilomyces fumosoroseus* and *Steinernema feltiae* were not effective at economically feasible concentrations. Hydrogen peroxide treatments of rockwool prevented algal growth and consequently fly emergence, but even the smallest effective concentration reduced plant growth. Change of cropping system, use of large yellow-sticky sheets on the walls and strict sanitation methods resulted in 6-fold decrease of the fly population when compared to the old cropping system in the two previous years. Basic biological parameters of the flies were determined in greenhouse and laboratory experiments.

Introduction

Scatella stagnalis (Diptera, Ephydridae) occurs commonly in greenhouses when green algae are available for feeding. Studies have shown the difficulty of controlling the flies with chemicals (e.g. Lindquist & Casey 1994). Despite the fact that shore flies do not harm plants directly by their feeding, they can cause indirect damage to plants by vectoring propagules of plant diseases (Stanghellini 1991). A sufficient justification for control of shore flies, however, is the nuisance they pose for workers when multiplying rapidly in hot weather.

In 1993-95, research was conducted to develop non-chemical methods to manage shore fly populations in a cucumber seedling crop heavily infested with the pest. The crop system is characterized by a short crop cycle of 23 days and a large number of plants (68 000) produced in 9x9 or 10x10 cm rockwool cubes during the 2,5 months' period in June-August when shore flies form a problem.The so far poorly known basic biology of *S. stagnalis* in greenhouse conditions was studied to get better understanding of management possibilities.

Material and methods

Experiments were run utilizing a simple method of letting the flies breed on rockwool cubes overgrown with green algae. Developmental time of shore fly eggs to adults, mortality during development and sex-ratio was studied in an experimental greenhouse at fluctuating temperatures (23-34 ^{o}C). In test I the development of 10 eggs was followed into adults in detail at 12-24 hour intervals on mini-cubes of rockwool. In test II flies were let to lay eggs on larger rockwool cubes, the eggs were counted and let to develop into adults which were counted after 12 days from egg-laying. Fecundity and longevity were studied at constant 25^{o}C by placing one-day-old females singly with a fresh male in plastic tubes sealed with a piece of rockwool at the bottom and by counting the eggs from it at one or two day intervals.

The effect on shore flies of different concentrations of *Paecilomyces fumosoroseus* (Pfr-94, Biobest, Belgium), applied either as granules that sporulated on the substrate or as water suspension, was studied in repeated growth chamber and greenhouse experiments. In a large scale experiment 80 m^2 of rockwool cubes was sprayed with low concentrations of Pfr-94 (0.05 g/cube) in the beginning of five successive three-week crop cycles to see whether epizootics could be induced in the fly population using economically feasible concentrations of the preparation. The population dynamics of the flies in rockwool was followed weekly during each crop cycle by extracting the larvae with Tullgren-funnels, and by letting flies hatch from cubes for 12 days. The persistence of Pfr-94 in rockwool during the three-week crop cycle was studied in an experimental greenhouse at 18-20°C and in the practical greenhouse at fluctuating temperatures by employing a selective agar-medium and the plate-dilution method. *Steinernema feltiae* (Nemasys®, Biobest) at concentrations of 200, 500, 1000, 1250 and 6250 per cm^2 of rockwool substrate were tested against larvae in one growth chamber and one greenhouse experiment.

Three tests with 10 concentrations of hydrogen peroxide (3-148 ‰, 0.5 dl per 10x10 cm cube) were conducted to reduce algal growth on rockwool. Hydrogen peroxide was applied to cubes upon planting one-week old seedlings to them, and its effect on the number of leaves, dry weight of plants and the number of shore flies emerging from cubes was determined after one and two weeks from the treatments. A comparison was made to cubes covered with a piece of grey cloth of the size of the cube surface.

The cropping system was changed in 1995 to slow down the flies' reproduction. The old cropping system was to sow cucumber seeds directly to the rockwool cubes in the greenhouse and grow them there for 23 days. Fly eggs laid during the first and second week hatched into adults in the greenhouse during the crop cycle. In the new system, the seeds were sown in small rockwool pots in a germination room free of flies where the plants grew for one week, they were then replanted to bigger cubes in the greenhouse. Thus, the substrate was now exposed to flies only for two weeks, and only the first week's eggs had time to develop into adults in the greenhouse. Knowing the proportion of flies that hatched from one, two and three week old cubes it could be calculated that change of cropping system alone should result in roughly 10-fold decrease of fly numbers. Large sheets of yellow-sticky traps ("Mastertrap, Oecos Ltd, Eng-land) were hung in the compartments to form a constant 0.6 meter wide band of yellow-sticky surface on all the four walls. Strict sanitation methods were adopted to keep the rooms free of standing water, weeds and debris. In 1993-95, the population size of flies in two greenhouse compartments was monitored with four yellow sticky traps /1000m^2 hung above the crop. In 1994-95 traps were placed also under eight tables in the most persistently infested compartment.

Results and discussion

Shore flies have an enormous population build-up capacity due to a short development time and large fecundity of females (Table 1). The cumulative number of adults emerging from a 9 x 9 cm rockwool cube during one crop cycle in 1994 in the 23-day cropping system varied between 198 and 307 (roughly 17 million from the 68 000 cubes in 2.5 months). This rapid reproduction would pose a huge challenge for parasitoids or predators in order to cope with, particularly in short-term, heavily irrigated crops like cucumber seedlings in rockwool. Furthermore, biocontrol agents would be removed regularly with the cubes upon selling the plants. In these conditions microbiological methods are likely to be more suitable against the pest.

Pfr-94 at its best resulted in 71±15 % and 89 ±1 % control effects (means and s.e. for two experiments, n=8 per trmt) in growth chamber conditions when applied at high concenrations of 0.5 grams water suspension or 1.2 grams of dry granules, respectively, per 81 cm^2 rockwool cubes. In practical conditions with heavier irrigation, application of 0.7 g granules per 100 cm^2 cube resulted only in 29.2±12.7 % control (mean and s.e for two experiments). Treatments of cubes in the beginning of the crop cycle with a low concentration of Pfr-94 did not reduce fly numbers. Infected pupae, but not adults, were occasionally found.The cumulative number of flies hatching from Pfr-94 treated cubes in three weeks was roughly 20 % less than from untreated cubes, but the difference was statistically significant only in one experiment out of five. No effect was seen on the number of larvae per cube. The amount of fungus applied onto the rockwool as water suspension decreased to 30 % of the original in one week both in the experimental and practical greenhouses and remained at that level for the last two weeks.

Table 1. Basic biological parameters of *Scatella stagnalis*. s.e.=standard error of the mean.

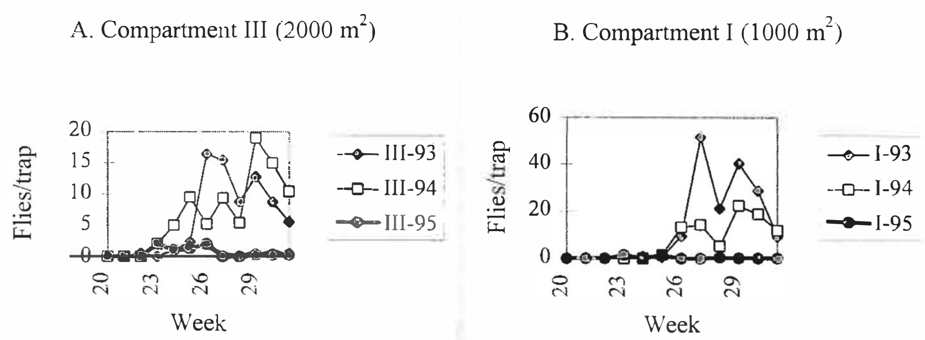
Parameter	Mean ± s.e.	Min - max	n
Egg development time[1]	1.05 ± 0.04 days	1 - 1.5	22
Larval development time[1]	5.2 ± 0.12 days	4 - 6.5	17
Pupal development time[1]	3.8 ± 0.18 days	3 - 5	12
Total from egg to adult[1]	10 ± 0.21 days	9 - 11	12
Percentage hatched eggs (test I)[1]	86.7 ± 2.9 %	0 - 100	24
Percentage hatched eggs that developed to adults (test I)[1]	63.2 ± 5.4 %	0 - 100	24
Percentage all eggs that developed to adults (test I)[1]	55.4 ± 5.4 %	0 - 100	24
Percentage all eggs that developed to adults (test II)[1]	51 ± 7.6 %	23 - 100	18
Longevity, females[2]	14.5 ± 0.7 days	5 - 21	36
Longevity, males[2]	22.8 ± 0.7 days	17 - 29	22
Preoviposition period[2]	3.2 ± 0.1 days	2 - 5	36
Life-time fecundity per female[2]	314.9 ± 18.8 eggs	37 - 563	36
Eggs per day per female[2]	21.6 ± 1.0	3.4 -35.9	36
Percentage females in the population	53.4 %		264

[1] studied at a fluctuating temperature (23-34°C) in the greenhouse in natural light conditions; [2] studied at a constant temperature of 25°C in laboratory in natural light conditions of Finnish summer

S. feltiae at concentrations of 1250 and 6250 infectives/cm^2 of rockwool reduced fly emergence by 86 % (std 16.7, n=6 cubes) and 100 % (std 0, n=6 cubes; results from one experiment). Economically more feasible concentrations of 200, 500 and 1000 infectives/cm^2 in the large greenhouse reduced the number of emerging flies only by 23, 27 and 53 %, respectively (n=15 cubes/trmt, one experiment).

Hydrogen peroxide concentrations 25, 34, 37, 98 and 148 ‰ resulted in 73-100 % control efficiency of flies during the first week after treatment. There was no effect if treatments were done after algae had started to grow on the rockwool. In most cases the control efficiency decreased below 50 % during the second week as algae resumed growth. The best combination of good control efficiency of flies and minimum plant growth reduction was obtained by 25 ‰ hydrogen peroxide: control efficiency of flies 82±9 % and dry weight of plants 87±6 % of the untreated controls after one week, and 29±29 % and 87±3.2 % after two weeks, respectively (means and s.e. for two experiments). However, the growth reduction of plants was unacceptable to the grower. Best results were obtained using the cloth cover: no effect on plant, control efficiency of flies 95 % during the first and 82 % during the second week. The method is too labour extensive in large scale use unless developed further.

Based on weekly trap catches averaged over the summer, the change of cropping system combined with the use of big yellow-sticky traps on the walls and strict sanitation methods resulted in 10 and 11-fold decrease of catches of *Scatella* in traps over crop in compartment



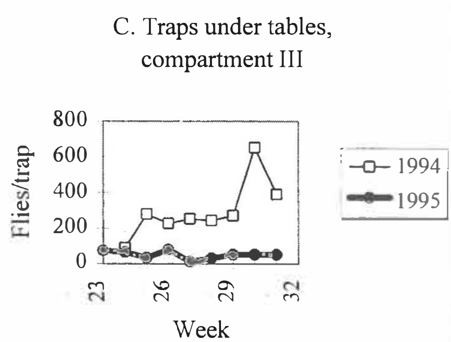


Fig. 1. Shore flies in yellow sticky traps placed over crop in two compartments of the cucumber seedling greenhouse in 1993-95 (A and B; means of four traps/ room), and under tables in one room in 1994-95 (C; means of eight traps). Cropping system was changed in 1995 to reduce the substrate's exposure to flies and thus to slow down the increase of the fly population.

III in 1995 compared to 1993 and 1994, respectively (Fig. 1). Catches in traps under tables showed a 5.9-fold decrease. The difference was likely due to the lowered attraction of small sticky traps above the crop in the presence of large sticky traps on walls. In compartment I the number of flies in traps over crop decreased by a factor of 39 and 28 compared to 1993 and 1994, respectively. Placing sticky traps under tables is a more effective way of monitoring *Scatella* than traps above the crop, as the flies sit in shadow during hot weather and outside their peak activity period of 12-18 in the afternoon (cf. Nielsen & Nielsen 1979).

Cultural and mechanical management practices alone alleviated the shore fly situation considerably in the cucumber seedling crop. No effective biological control methods applicable to this crop system could be found so far. In another greenhouse producing rose sticklings in rockwool an aggressive epizootic of *Beauveria bassiana* completely wiped out shore flies. Studies are underway on the feasibility of integrating the isolated strain of *B. bassiana* with other control methods of shore flies.

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Toxicity of the fungal pathogen *Paecilomyces fumosoroseus* strain Apopka 97 to the greenhouse whitefly *Trialeurodes vaporariorum* and the parasitoid *Encarsia formosa*, and first results of a control experiment in glasshouse tomatoes.

M. Van de Veire & D. Degheele

University of Ghent
Faculty of Agricultural and Applied Biological Sciences
Laboratory of Agrozoology
Coupure links, 653, B- 9000 Ghent

Abstract

Paecilomyces fumosoroseus (PFR) gave excellent control of the different greenhouse whitefly developmental stages in laboratory experiments under optimal conditions for growth and sporulation of the fungus, without adverse effects on the important parasitoid *Encarsia formosa*. The results were confirmed in a commercial glasshouse in which poor biological control of the greenhouse whitefly with *E. formosa* was corrected by a 2-fold application of the entomopathogen.

Introduction

Entomopathogenic fungi, e.g. *Aschersonia aleyrodis* Webber (Deuteromycetes: Coelomycetes), *Verticillium lecanii* (Zimmerman) Viégas (Deuteromycetes: Moniliales), have been forwarded as potential biocontrol agents for the greenhouse whitefly, *Trialeurodes vaporariorum* Westwood (Hemiptera: Aleyrodidae). One of the problems was the RH which had to be kept very high (>80%) for a considerable period (2 days) in the glasshouse. With the fungus *Paecilomyces fumosoroseus* (Wize) Brown & Smith (Deuteromycetes: Hyphomycetes), the RH requirements are less severe, i.e. a high RH (ca. 100%) during the first 12 hours would already be sufficient for the mycelium to grow through the insect cuticle.

P. fumosoroseus strain Apopka 97 was isolated in 1986 from the mealybug *Phenococcus solani* (Hemiptera: Pseudococcidae) by Dr. L. Osborne (Bolckmans et al. 1995). It is a naturally occuring fungus in most countries of the world. In contrast with other entomopathogens (e.g. *A. aleyrodis*, *V. lecanii*), *PFR* exerts a broader spectrum of activity and may infest not only Homoptera, but also Diptera, Lepidoptera, Coleoptera (Osborne & Landa, 1992).

Although very efficient insect growth regulators (buprofezin, pyriproxyfen) and products with new modes of action (diafenthiuron) now can be applied for whitefly control in many European countries, either alone or in combination with *Encarsia formosa* Gahan (Hymenoptera: Chalcididae) (for selective chemical correction), within the concept of IPM, e.g. insect resistance management, any biocontrol agent used to correct poor biocontrol with *E. formosa,* is highly desirable.

In the current work the toxicity of *PFR* on all whitefly stages and black scales has been studied, together with the possible use of the microbial product in IPM schemes for whitefly control on glasshouse tomatoes.

Materials and methods

1. Laboratory experiments.

Bean seedlings (*Phaseolus vulgaris* L.), with 2 leaves were infested with adult whiteflies (> 100

per bean) for 2 days. Then the insects were removed and the leaves were cut and placed in moist vermiculite for rooting at 20-22°C, RH: 70% and L/D: 16/8 in climatic chambers.
At the appropriate time, the following developmental stages of the greenhouse whitefly were sprayed with *PFR*: white eggs, lila eggs, L1-L2-L3 larvae, white scales and adults. Also just blackened scales, parasitized by *E. formosa*, were exposed to *PFR*.
PFR was sprayed with a 300 ml handsprayer at a rate of 1 g product/liter water (*PFR* 20% WG, containing 1. 10^9 CFU/g). The fungal product was dissolved in tap water and stirred for 1 hour to get an optimal spraying solution. After spraying, the bean leaves, containing the appropriate whitefly stage and parasitized whitefly stage, were placed in a "drum" cell, with 2 plexiglass rings of 9 cm diameter, 6 cm height, with the roots hanging in tap water in a support, while the leaves themselves were inside the cell, in which the RH was ca. 100%, temperature 20-22°C and photoperiod L/D: 16/8. The leaves were kept for 24 hours at 100% RH, then they were removed from the drum cells and kept in the laboratory, in which the ambient RH ranged between 40 and 50%, measured with a psychrometer.
Each treatment was carried out in 3 replicates. For every whitefly stage, an untreated control was run. The evaluation of the *PFR*-effect was done by counting, at least one week after the treatment, the number of hatched and nonhatched (dead) eggs, the number of live and dead larvae, scales and adults. Mortality of the different stages was calculated with correction for control mortality (Abbott).

2. Glasshouse experiment: control of the greenhouse whitefly in tomatoes.

PFR was sprayed on the under and upper side of tomato leaves in a commercial tomato crop grown in rockwool and heavily infested with the greenhouse whitefly. The infestation of whiteflies was due to poor biocontrol with the parasitic wasp *E. formosa*.
The application of *PFR* was done with a 10 liter handdriven knapsack sprayer in the late afternoon when RH was close to 100 %, at a rate of 1 g product/liter water and on 2 dates (June 7th, June 13th 1995). The amount of spray solution corresponded to 2,000 liter/ha. A surfactant (Citowett) was added to the spray solution (2.5 g/10 liter water) to enhance spread of the *PFR* spores. Then, the glasshouse was closed so as to ensure a high RH up to the following morning. Mean temperatures during the experimental periode were 20°C min. and 30-35°C maximum. The highest possible RH was thus assured for at least 15 hours.
Fifty tomatoplants in one row were treated with the entomopathogen, while 42 plants from the same row were not treated at all.
The *PFR* effect was assessed by counting on leaf parts (0.78 cm^2) live larvae, dead larvae, live and dead scales, black scales from 1 leaf per plant (n = 15 plants) on 2 dates: June 28th, July 6th. Mortality is expressed by the no. of dead larvae and scales on the total number of larvae and scales.

Results

1. Laboratory experiments.

The effect of *PFR* on the greenhouse whitefly developmental stages is summarized in Table 1.

Table 1. Toxicity of *PFR* on whitefly eggs, larvae, scales and adults.

Greenhouse whitefly stage	*Mortality following PFR treatment (%) (corrected for control mortality)*
White eggs	97.4
Lila eggs	91.6
L1 larvae	90.9
L2 larvae	57.6
L3 larvae	89
White scales	84.6
Black scales	1.8
Adults	97.3

PFR was highly toxic to the egg stage, the L1, L3, the white scale and the adult stage, but was significantly less toxic to the L2 stage. This is most probably due to the fact that the L2 stage of the greenhouse whitefly only lasts 2 days (under normal conditions) and that the old cuticle is shed while the *PFR* spores have not yet germinated through it. *PFR* did not affect parasitized whitefly scales.
PFR did not kill all whitefly larval stages, in particular the L2 stage, in contrast with some highly selective chemicals like buprofezin and pyriproxyfen which kill > 95-99% of the larvae. The latter are so efficient larvicides that the parasitic wasp *E. formosa* could have feeding and reproduction problems due to a shortage of host larvae. In the case of IPM of the greenhouse whitefly, and taking into consideration long lasting efficient control, *PFR* might become an important correction agent for poor biological control with the wasp *E. formosa*.

2. Glasshouse experiment: control of the greenhouse whitefly in tomatoes.

The results of the toxicity of *PFR* on the greenhouse whitefly is given in Table 2.

Table 2. Toxicity of *PFR* to greenhouse whitefly larvae and scales in a glasshouse experiment.

	Mortality (%) 14 DAT (2nd)	Mortality (%) 23 DAT (2nd)
PFR Apopka strain 97	63.3 (± 16.1)*	78.8 (± 24)
Control (untreated)	17.3 (± 17.6)	14.0 (± 17)

* between parenthesis: S.D.

The results obtained in the laboratory are confirmed in the glasshouse experiment. The entomopathogeneous fungus *P. fumosoroseus* controlled the greenhouse whitefly to ca. 80% 23 days after treatment, while the surviving scales not only could be parasitized by the parasitic wasp *E. formosa* but remained viable since adult wasps developed in 80% of them (n= 180 black scales, collected on July 7th). The overall survival of the greenhouse whitefly was 1-2% (no. of white scales on the total no. of larvae and scales) in the *PFR* treatment, while this was 10% in the untreated control. This resulted in an excellent integrated control of the greenhouse whitefly.

Conclusions

The entomopathogen *Paecilomyces fumosoroseus* can reduce the greenhouse whitefly populations slowly in highly infested glasshouse tomatoes while it has no adverse effects on its parasitoid *E. formosa*.

The toxicity of this fungus cannot be compared with those of insect growth regulators, e.g. buprofezin or pyriproxyfen, but this may be an advantage because surviving host larvae can be parasitized by *E. formosa,* while in the case of the high percentage killed by buprofezin or pyriproxyfen the parasitoid may disappear.

PFR, used as a biological correction agent for poor biocontrol of the greenhouse whitefly with *E. formosa*, can become an important product in IPM of the greenhouse whitefly, and contribute to a reliable and sustainable control of the latter.

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Methodology for developing and evaluating monitoring programs for crop pests and diseases

W. van der Werf[1], J.P. Nyrop[2], M.R. Binns[3] & J. Kovach[2]

[1] Wageningen Agricultural University, Department of Theoretical Production Ecology, P.O.B. 430, 6700 AK Wageningen, the Netherlands

[2] Cornell University, New York State Agricultural Experiment Station, Department of Entomology, Geneva, New York 14456-0462, USA

[3] Agriculture and Agri-Food Canada, Research Branch, Ottawa, Ontario, Canada K1A OC6

ABSTRACT

Monitoring of pests or diseases over time is often required to schedule interventions (biological, chemical or other) at the right time. To minimize sampling effort in monitoring programs, risks of overtime detection of damaging outbreaks must be balanced against the labour costs of intensive monitoring. This paper advocates a structured approach to designing monitoring programs. Computer simulation of sampling over time, pest population dynamics, and pest damage is used to evaluate options for monitoring programs. The best monitoring program in the simulations is tested in the field. This approach has worked well for developing an optimal monitoring program for European red mite in apples. The methodology is applicable in many other crop-pest systems.

Many important pests (e.g. mites, aphids, trips) and diseases (rusts, mildews, Botrytis spp.) have multiple generations per year and pose a risk of outbreak over an extended period of time. Whether and when intervention is necessary depends on driving variables such as weather and natural antagonists, and is difficult to predict. Monitoring (i.e. sampling over time) is therefore often required. Several approaches have been developed to schedule sampling over a pest or disease season (Zadoks, 1989; Nyrop et al., 1994; Pedigo, 1994; Wilson, 1994), but compared to the vast body of theory and practical approaches on pest sampling (Pedigo & Buntin, 1994), the development of monitoring methods is in its infancy. Little work on monitoring theory has been done, despite the practical relevance of monitoring and the potentially large benefits of optimizing the methods that are currently used.

Nyrop et al. (1994) formulated a methodology for developing and evaluating monitoring methods which comprises five steps (Fig. 1). They distinguish between sampling plans, which are defined as procedures used to estimate or classify density, and monitoring protocols, which are defined as the way in which sampling plans are used to track density through time.

1. Construction of a set sampling plans that are used to determine whether intervention is necessary or not. If no intervention is necessary, the time at which the pest should be resampled is indicated. For red spider mite in apples (*Panonychus ulmi* Koch), Nyrop et al. (1994) used sampling schemes that decided between immediate intervention, resampling after one week and resampling after two weeks (Fig. 2).
2. Monte Carlo simulation of the performance of each of the sampling plans in terms of 1) the probability of taking one of the possible decisions, and 2) the average number of sample units required to make a decision (Fig. 3). These two criteria are functions of the true pest density only, assuming that the variance of population density is a function of the mean density. Nyrop et al. (1994) represented the sampling distribution of red spider mites over leaves with a negative binomial distribution, using a power relationship between the variance and the mean to calculate the dispersion parameter *k*.

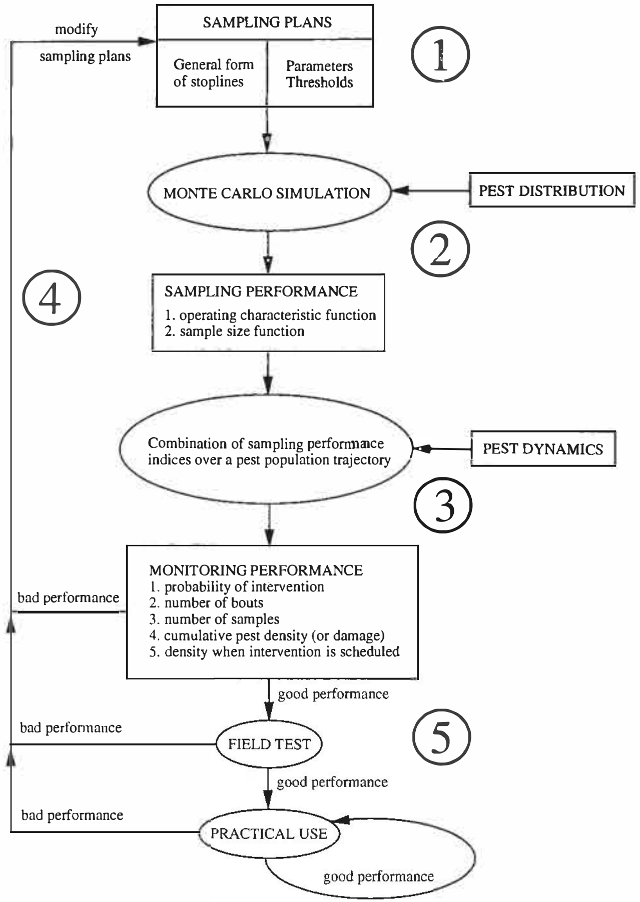

Fig. 1: five steps in developing and evaluating a monitoring protocol

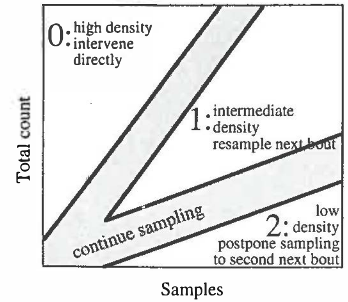

Fig. 2: Protocol for tripartite sequential classification. Leaves are inspected one by one. The cumulative number of 'positive' leaves (vertical axis) is plotted against the running total number of inspected leaves. As long as the point indicating the result of sampling is in the grey areas, sampling has to be continued. As soon as the point moves into one of the three white areas, the result of sampling is reliable enough to take a decision. The decisions are intervene (0), resample at next occasion (1), and resample at second next occasion (2).

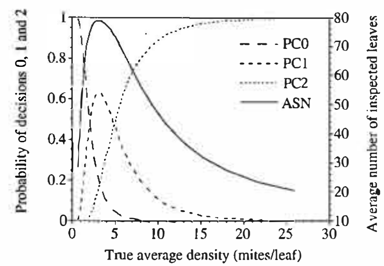

Fig. 3: Performance characteristics of a tripartite sequential classification sampling plan.
Left axis: Probability of making one of three alternative Classifications:
PC0 - - - intervene,
PC1 ----- resample at next occasion, and
PC2 ········ resample at second next occasion.
Right axis: ASN = average number of leaves (——) inspected before taking a decision

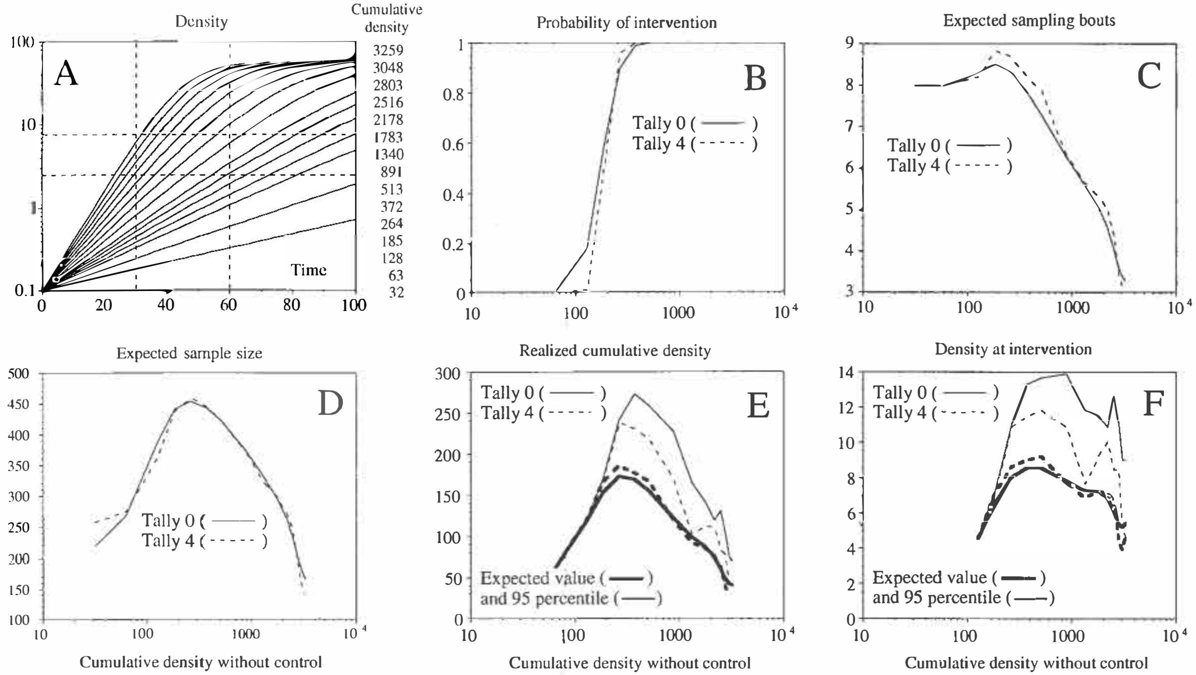

Fig. 4: Simulated performance characteristics of two monitoring protocols, based on tripartite presence/absence classification, when monitoring mite populations over a period of 90 days. The comparison is made using logistic population trajectories with a maximum level of 50 mites/leaf and differing relative growth rates (A). Both protocols are based on critical densities of 2.5, 5 and 7.5. mites/leaf over the time periods 0-30, 31-60 and 61-90 days. Protocol 1 (**drawn lines**) is based on simple presence/absence monitoring (**tally 0**). Protocol 2 (**hatched lines**) is based on counting leaves with more than 4 mites/leaf (**tally 4**), which yields a more precise relationship between incidence and density, but is more laborious to execute in the field. The performance criteria are: (B) the probability of intervention, (C) the expected number of sampling bouts, (D) The expected total number of sample units, (E) the accumulated number of mite-days per leaf, and (F) mite density at the time of scheduled intervention. Performance criteria are quite similar for the two protocols, except for the 95th percentiles of density at intervention and cumulative mite density. These measures for 'risk' are higher for the less accurate presence/absence based monitoring method. Curves for the 95 percentiles are jagged due to the stochastic nature of the simulations.

3. Calculation of the performance of a chain of sampling plans used over a season to monitor density through time. Performance is calculated by combining the performance criteria of the sampling plans (functions of density) with simulated or observed trajectories of density over time. The performance of a monitoring protocol for a given set of population trajectories is characterized by five criteria:
   - the probability of intervening
   - the cumulative pest density up till the moment of intervention
   - the density at the moment of intervention
   - the total number of sampling bouts scheduled
   - the total number of samples taken in all bouts.

   An example of simulated performance is given in Fig. 4. The overall performance depends on the performance of each of the sampling schemes for given densities and on the population trajectorie(s). Schemes that have good performance for slowly growing pest populations (biological control!) might have bad performance for rapidly growing populations, and vice versa (Binns et al., in press).
4. Next, the parameters of sampling plans constituting the monitoring protocol are varied, in order to identify the set of sampling plans that gives the most desirable performance. Thereby, the performance criteria are weighted by expert judgement.
5. The best monitoring protocol resulting from the iterative simulation process is tested in the field. If its favourable performance is confirmed, it can be extended to practice. The monitoring scheme developed by Nyrop et al. (1994) is currently recommended to and used by New York apple growers and field scouts (Wilcox et al., 1995).

This procedure of developing and analysing the performance of monitoring protocols by simulating sampling and population dynamical processes provides two advantages. The first is that insight is gained in the relationship between parameters of sampling plans and the performance of monitoring protocols. The second advantage is that aspects of sampling methods that give good performance in the monitoring context may be deliberately sought, and optimized. For instance, Nyrop et al. detected by their simulations that the intervention thresholds for red spider mite that were used in practice, were more risk averse (had a tendency towards intervening) than was thought. It was also found that monitoring protocols consisting of low precision sampling plans with raised thresholds (to avoid unnecessary intervention) gave as good protection against population outbreaks as high precision plans, but with much less sampling effort. In the future, thresholds may be raised on the basis of these findings. This will improve the chances for biological control.

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Calculation of the influence of the vertical distribution of feeding injury by two-spotted spider mite (*Tetranychus urticae*) on photosynthesis and respiration of cucumber

W. van der Werf[1], H. Gijzen[2], W.A.H. Rossing[1], R.T. Dierkx[1] & A. Tomczyk[3]

[1] Wageningen Agric. Univ., Dept of Theoretical Production Ecology, P.O.B. 430, 6700 AK Wageningen, the Netherlands

[2] Wageningen Agric. Univ., Dept of Horticulture, Haagsteeg 3, 6708 PM Wageningen, the Netherlands

[3] Warsaw Agric. Univ., Dept. of Applied Entomology, Nowoursynowska 166, 02-766 Warsaw, Poland

ABSTRACT

The relationship between the severity of pest attack and the amount of crop damage depends on the position of injury in the crop. We use a mechanistic simulation model for daily photosynthesis and respiration of a cucumber crop to quantify the relationship. Two effects of mite feeding on the functioning of leaves are taken into account: the effect on gross photosynthesis and the effect on respiration. The calculations show that the reduction of photosynthesis is greatest when injury occurs predominantly at the top of the canopy. The effect of mite injury on respiration is also affected by the injury profile, but the effects are substantially smaller than for photosynthesis. The calculations suggest that rather high levels of injury, up to 40%, can be tolerated. The results of these calculations are guidelines when developing sampling plans for mite damage with the purpose of estimating the relationship between injury and damage.

INTRODUCTION

Spider mites are important pests in a wide range of crops (Helle & Sabelis, 1985). They feed on the contents of mesophyll cells (van de Vrie et al., 1972), causing leaf bronzing or browning and early senescence. In earlier work (Tomczyk, 1989; Tomczyk et al., in prep.), we quantified three mechanisms by which two-spotted spider mites (*Tetranychus urticae)* affect the carbon economy of cucumber. Photosynthesis at light saturation is initially stimulated by a small percentage of spotted leaf area. Maximum stimulation (about 9%) is reached at about 16% leaf injury (Fig. 1A). Beyond this point, photosynthesis declines again. Dark respiration increases with leaf injury. It follows a saturation type of relationship characterized by a maximum respiration increase of 18 % and an initial slope of 1% respiration increase per % spotted leaf area (Fig. 1B). Biomass consumption by mites - as quantified by ^{14}C labeling - amounts to approximately 10 µg dry matter per mite per day.

The three mechanisms were included in a dynamic simulation model of the carbon economy and growth of cucumber plants under optimal water- and nutrient supply to ascertain whether these mechanisms can account for the reduction of yield, caused by spider mites in glasshouses, and to determine the relative importance of the three mechanisms. The model was validated using data from three glasshouse experiments, and found suitable for making estimates of the growth of mite-infested cucumber under optimal water- and nutrient supply and an ambient CO_2 concentration of 350 µl/l.

Sensitivity analysis of the model showed that at high mite densities, the reduction of the maximum rate of photosynthesis accounts for about 70% of total damage, assimilate withdrawal for 15-20% and increased respiration for 10-15%. At intermediate and low mite densities, there

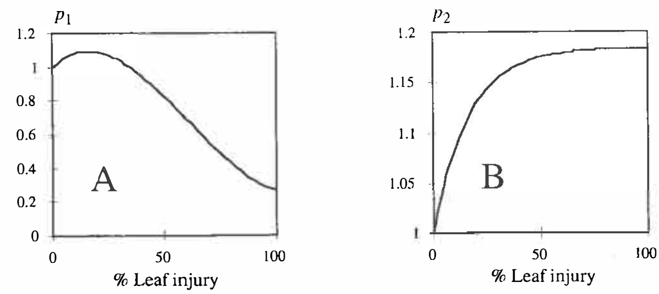

Fig. 1: Relationship between gross photosynthesis (as proportion of photosynthesis of un-injured leaves, p_1) and leaf injury by mites (A) and between maintenance respiration (as proportion of maintenance respiration of un-injured leaves, p_2) and leaf injury by mites (B; Tomczyk et al., in prep.).

was a small positive effect of mites on photosynthesis, but this effect was overshadowed by the negative influences of the other two damage mechanisms.
In this paper we describe simulation experiments with the validated model. The purpose of these simulations is to estimate the effect of different levels of mite injury on crop photosynthesis under bright and dim light conditions and to determine the influence of the vertical profile of injury on crop photosynthesis.

MATERIALS & METHODS

We use the model ASKAM (Gijzen, 1992). This model calculates daily photosynthesis of a standard cucumber crop (e.g. leaf area index = 3), based on the amount and angle of incidence of incoming radiation and on photosynthesis parameters. Calculations are made for an arbitrary spring day, 16 May. Two situations are distinguished: a sunny day and a cloudy day. For the sunny day, we take the 90% percentile of the observed probability distribution of incoming radiation: 24.79 MJ global radiation m^{-2} d^{-1}. For the cloudy day, we take the 10% percentile: 7.73 MJ global radiation m^{-2} d^{-1}. Leaf canopy is subdivided in layers of 0.03 LAI units thickness. Leaf injury is distributed over these layers according to five different profiles (Fig. 2):

1. homogeneous;
2. linear decrease from a maximum percentage at the top of the canopy (equal to twice the average leaf injury) to 0 at the bottom. For leaf injuries above 50%, the linear decrease is from 100% at the top of the canopy to a minimum percentage at the bottom. This minimum percentage is equal to twice the average percentage leaf injury minus 100;
3. as 2, but with the highest leaf injury at the bottom;
4. 100% leaf injury in the top x leaf layers, where x is the average percentage leaf injury;
5. as 4, but with injury concentrated at the bottom.

The effect of mite injury was included in the model using two equations, one expressing the maximum rate of gross photosynthesis (for each leaf layer), and the other expressing the rate of maintenance respiration of leaves, both depending on leaf injury (Fig. 1).

1: $p_1 = 2.368\ 10^{-6}\ x^3 - 0.000431\ x^2 + 0.0121\ x + 1$

2: $p_2 = 1 + 0.184\ (1 - e^{-0.011\ x/0.184})$

In these equations, p_1 and p_2 are multipliers for gross photosynthesis and leaf respiration in a leaf layer, while x is leaf injury in that layer.

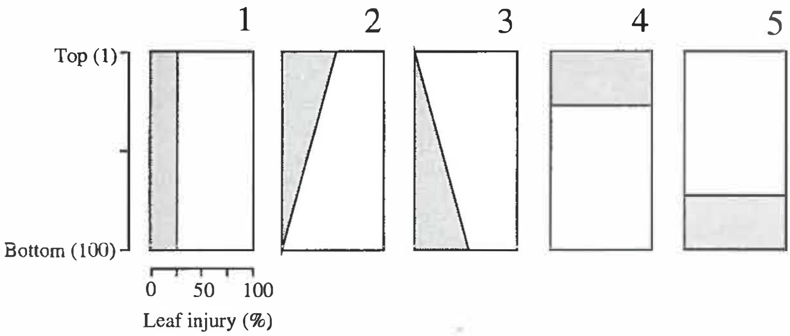

Fig. 2: Five injury profiles used in simulations of the effect of mite injury on crop photosynthesis of cucumber. Here, the profiles represent a total injury of 25%.

RESULTS

For the profiles 1, 2 and 3, gross photosynthesis has an optimum response to leaf injury (Fig. 3A,B). The shape of the responses is similar for high and low light intensities. The maximum stimulation of photosynthesis is in the order of 4% at high light intensity and 1% at low light intensity. Profiles 4 and 5 lack the stimulation effect because they have either 0 or 100% leaf injury in a layer, and no intermediate injuries at which stimulation can occur. Thus, strong clustering of injury results in greater photosynthesis reduction at low to intermediate total leaf injuries. The reduction of photosynthesis is greatest for the profiles where injury is concentrated in the top of the canopy (2 and 4).

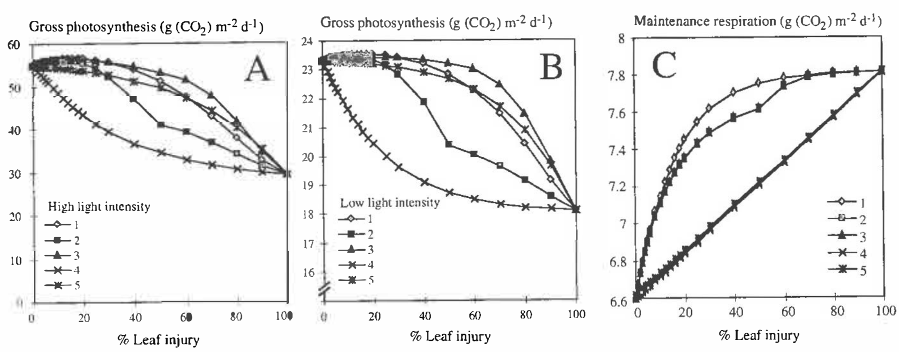

Fig. 3: Gross photosynthesis at two light intensities (A,B), and crop maintenance respiration (C) of a standard cucumber canopy with different degrees of leaf injury by mites (x-axis), for five profiles of mite injury over leaf layers (cf. Fig. 1).

The effect of mite injury on maintenance respiration is greatest when a homogeneous profile is assumed (profile 1 in Fig. 3C). This is because the relationship between respiration in a layer and injury in that layer is characterized by 'diminishing returns' (Fig. 1B). The greatest stimulation of respiration is achieved by 'adding' injury to the layer with the lowest injury, resulting in a homogeneous distribution giving the greatest stimulation. Profiles 2 and 3 have the same respiration-injury relationship, and so do profiles 4 and 5. The similarity is due to the fact that for respiration, light intensity plays no role. Hence, the profile can be flipped vertically without consequence for calculated respiration. The difference between the profiles is maximally 1 g (CO_2) m^{-2} d^{-1}, which is small compared to the differences in calculated gross photosynthesis among profiles. Hence, in the discussion of these calculations, we concentrate on gross photosynthesis.

DISCUSSION

This paper is a theoretical extrapolation based on empirical quantification of mechanisms of damage by mites and the incorporation of these mechanisms in a validated crop growth model. The objective is to obtain estimates of the influence of the vertical profile of mite injury on damage that results from such injury, based on knowledge about crop physiological effects of these mites. The highest reduction of photosynthesis occurs when injury is concentrated in the top of the canopy. In practice, injury done by *T. urticae* will often be concentrated on the older leaves, in lower leaf layers, or be distributed more or less homogeneously throughout the canopy. Simulations indicate that for these cases, the relationship between injury and photosynthesis is only marginally affected by the shape of the injury profile. This suggests that precise observations of the vertical distribution of injury are not necessary to calculate expected damage. The simulations also suggest that for leaf injuries up to about 40%, the reduction of photosynthesis is rather insignificant, provided injury is in lower layers and LAI is not less than 3. This finding suggests that rather high levels of injury can be tolerated, even if the effects of mites on respiration and their assimilate withdrawal are taken into account when calculating their impact. For mite species that feed more predominantly in the higher leaf layers, such as *T. cinnabarinus* (Tomczyk et al., 1992), different conclusions would be drawn.

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BIOLOGY OF *ORIUS SAUTERI* (POPPIUS) AND ITS POTENTIAL AS A BIOCONTROL AGENT FOR *THRIPS PALMI* KARNY

Eizi Yano
National Institute of Agro-Environmental Sciences, 3-1-1, Kannondai, Tsukuba, Ibaraki 305, Japan

ABSTRACT
Orius sauteri (Poppius) is found in Japan, China, Korea and the Russian Far East. It is mentioned as a predator of thrips, spider mites, aphids and eggs of lepidopterous insects in vegetable fields and orchards. It has shown to be effective in suppressing *Thrips palmi* Karny on eggplants in the field by insecticidal check methods. It also suppressed the increase of *T. palmi* on eggplants in greenhouse trials. Since *O. sauteri* is expected to be an effective biocontrol agent for *T. palmi* on greenhouse eggplants, rearing techniques in the laboratory are being developed using eggs of *Ephestia kuehniella* or acarid mites.

Biological studies on development and predation are also being carried out using *T. palmi* or aphids. Use of indigenous natural enemies such as *O. sauteri* is preferable to the use of imported species from the view point of the possible effect of imported species on indigenous species in agro-ecosystems. Four other indigenous *Orius* species are found in Japan. Comparative studies to evaluate the potential of these species are needed for future development of biological control with *Orius* species.

INTRODUCTION
Anthocorid predators of genus *Orius* are used for controlling *Frankliniella occidentalis* and *Thrips tabaci* on greenhouse vegetables in commercial greenhouses in western Europe (Riudavets, 1995). *Thrips palmi* is a serious pest of many greenhouse vegetables and *F. occidentalis* is causing serious damage to flowers and strawberries in Japan. As *T. palmi* and *F. occidentalis* are difficult to control with insecticides, biological control with *Orius* species seems an attractive alternative. One possibility is the use of species commercialized in Europe. However,indigenous *Orius* species are major predators in the field and on weeds in Japan. If imported species are released in greenhouses, they easily escape and interact with indigenous species. Such disturbance of agro-ecosystems should be avoided from the view point of environmental conservation.

STUDY OF ORIUS FOR BIOLOGICAL CONTROL OF THRIPS IN JAPAN
The use of indigenous *Orius* species is now being attempted in Japan, and *O. sauteri* is the most promising species. This has already been shown to be an effective predator of *T. palmi* in field experiments. This article reviews the biology *O. sauteri* and focuses on its use for biological control of *T. palmi*. Distribution, prey and host plants *O. sauteri* is a palaearctic species. It is found in Japan, Korea, China and the Russian Far East (Yasunaga, 1993; Yasunaga & Kashio, 1993). It is mentioned as a predator of thrips, aphids, spidermites and butterfly eggs. It is found on several vegetable plants including eggplants and cucumbers, field crops including potatoes, clovers and soybeans, and fruit crops including apples and citrus trees. Life history *O. sauteri* is a major predator of thrips in eggplant fields in Okayama, Japan. It reached a high density in July and September, in synchrony with the population fluctuation of thrips. *T. palmi* is the dominant species in September (Nagai, 1990a). It is also an important predator of aphids in a potato field in Hokkaido, Japan. It reached a high density in August, coincident with

the population peak of *Aphis gossypii* (Nakata, 1995a). Female adults of *O. sauteri* overwintered in the soil and their survival rate was affected by the soil moisture content (Wang, et al., 1994).

The preimaginal developmental time of *O. sauteri* at 25°C was 15.9, 11.4 and about 18 days when it was fed with nymphs of *Myzus persicae* (Nakata, 1995b), *Thrips palmi* (Nagai, 1989) and eggs of *Ephestia kuehniella* (Yano, unpublished), respectively. The nymphal developmental time at 25°C was 14.9 and 17.2 days when it was fed with nymphs of *Aphis gossypii* and corn pollen, respectively (Funao & Yoshiyasu, 1995). Rearing experiments of nymphal stages was conducted in China, with pollen of several plant species, aphids (*Lipaphis erysimi, Rhopalosiphum padi and Myzus persicae*), spider mites (*Tetranychus cinnabarinus*), eggs of the ricemoth (*Corcyra cephalonica*) and an artificial diet for lacewings (Zhou & Wang, 1989). *O. sauteri* was reported to show high survival rates during nymphal development when fed with arthropods and an artificial diet. High survival rates were also observed when it was raised on pollen of five plant species. Development to the fifth instar nymph was possible on an artificial diet for the plant hopper, *Laodelphax striatellus* (Nagai & Koyama, 1993).

Female fecundity varied with diet. Eggs of *E. keuhniella* are very good diets for high female fecundity. More than 100 eggs (Yano, unpublished) per female were produced on this diet, compared with 29.2 (Funao & Yoshiyasu, 1995) and 21.8 (Nagai, 1993) eggs when raised on nymphs of *A. gossypii* and larvae of *T. palmi*, respectively. Female longevity also varied with diet, being almost 1 month, 15.3 and 8.7 days when raised on eggs of *E. kuehniella*, nymphs of *A.gossypii* and larvae of *T. palmi*, respectively. *Orius* species usually need plant materials for oviposition. Bean pods are used for oviposition of species studied in Europe or North America. *O. sauteri* preferred soybean sprouts to young shoots of *Forsythia suspensa* and pods of *Phaseolus vulgaris* (Zhou, et al., 1991). Eggs of *E. kuehniella* or acarid mites have been used as diet and sprouts of soy beans or kidney beans have been used as oviposition materials for mass rearing of *O. sauteri* in Japan. Supply of water or fresh plants are needed for development and survival of *O. sauteri*.

Females of *O. sauteri* entered diapause when reared at 22°C under short photoperiods. The critical photoperiod for induction of diapause was between 12 and 13h (Kono, personal communication).

***O. sauteri* feeds on native species of thrips**, *T. palmi*, *T. setosus* and *Mycterothrips glycines*, in eggplant fields in Okayama (Nagai, 1990a). Four species of aphids, *Aphis gossypii, Aulacorthum solani, Macrosiphum euphorbiae and Myzus persicae* are listed as major prey species of *O. sauteri* in a potato field in Hokkaido (Nakata, 1994). *O. sauteri* was shown to feed on the eggs and larvae of the greenhouse whitefly, *Trialeurodes vaporariorum*, in the laboratory (Kajita, 1982). Laboratory experiments on selective predation of *O. sauteri* on *T. palmi*, *Tetranychus kanzawai and Aphis gossypii* showed that adult females prefer *T. palmi* most, followed by *T. kanzawai and A.gossypii*. An adult female was reported to eat 22 second instar larvae and 26 adults of *T. palmi* in 24h. The functional responses of nymphs and female adults of *O. sauteri* on these prey species showed Holling's type-II responses (Nagai, 1991).

POTENTIAL OF *ORIUS SAUTERI* AS CONTROL AGENT FOR *THRIPS PALMI*.
The effectiveness of *Orius sauteri* for suppressing *T. palmi* has been evaluated in different ways in Japan. Potted eggplants were introduced into a screencage, and both *T. palmi* and *O. sauteri* were released. After spraying with fenthion, which controls *O. sauteri* but does not affect *T. palmi*, *T. palmi* increased rapidly. Without application of fenthion, *T.palmi* was kept at a very low level (Nagai et al., 1988). Similar experiments was carried out in open fields of eggplants. When the eggplants were treated with fenthion, the peak density of *T. palmi* was four times as large as that on the untreated plants (Nagai, 1990a). Further experiments were also conducted using the selective pesticide, pyriproxyfen, which has a control effect on the pupal stage of *T. palmi* but is harmless to *O. sauteri*. *T. palmi* on eggplants decreased very rapidly after application of this pesticide, due to a combined effect of the pesticide and *O. sauteri* on the *T.palmi* population (Nagai,1990b).

Since *O. sauteri* has a suppressive effect on *T. palmi* in open fields of eggplants, it is expected to be a biocontrol agent for *T. palmi* on greenhouse eggplants. Different numbers of fifth instar nymphs of *O. sauteri* were released in four plots in a greenhouse containing eggplants 12 days after release of *T. palmi*. *T. palmi* was kept effectively below its economic injury level when more than 2 nymphs of *O. sauteri* per plant were released. Although *O. sauteri* seems to be a promising agent for biological control of *T. palmi* in greenhouses, several biotic or abiotic factors influence its effectiveness as a predator. The most important biological factor is the effect of the host plants of *T. palmi*. Cucumber is a better host plant for *T. palmi* oviposition and produces less amount of pollen than eggplant or sweet pepper, so that use of *O. sauteri* on cucumber is more difficult than on the other two crops. Furthermore, induction of reproductive diapause under short photoperiods makes the use of this species more difficult in winter.

Another complicating factor is the effect of native populations of *Orius* species in the environments surrounding the greenhouses. Since the greenhouse environment is not tightly isolated in Japan, native *Orius* species can migrate from surrounding fields into greenhouses easily from spring to autumn, when they are abundant in the field. Temperature is the most important physical factor to be considered. Predation and oviposition activity of *O. sauteri* are strongly dependent on temperature. Below 20°C, these activities decrease drastically in comparison with those at higher temperature (Nagai, personal communication). Temperature and photo period conditions vary with different cropping periods, so that appropriate cropping periods for biological control with *O. sauteri* can be assumed. It is expected that *T. palmi* would be controlled effectively from May to October. *O. sauteri* does not reproduce under low temperature and short photoperiod conditions in winter, which makes its use difficult under such conditions.

The time of release of *O. sauteri* and the initial density of *T. palmi* and *O. sauteri* are important and manageable factors, affecting the outcome of biological control. It was reported that there were no large differences in the suppressive effects when different numbers of *O. sauteri* nymphs between two and five per plant were released on eggplants in greenhouses (Kawai, 1995). Recommendations for future development of biological control of *T. palmi* with *O. sauteri* has been studied intensively in Japan because it is the most common and major predator species in the field. However, four other species of *Orius*, *O. similis*, *O.minutus*, *O. tantillus and O.nagaii*, are recognized as indigenous species in Japan. The disadvantage of *O. sauteri* is the induction of diapause and inactivity under low temperature and short photoperiod conditions.

The species of subtropical origin, *O. similis and O. tantillus*, are expected to reproduce under short photoperiod conditions without entering diapause. Comparative studies of the life history and behaviour of these species are needed for future development of biological control of *T. palmi* with *Orius* species. Such studies are now being carried out in Italy, with the aimof evaluating *Orius* species for biological control of *F. occidentalis* (Tomasini & Nicoli, 1993).

Independent comparison of biological characteristics related to the effectiveness of *Orius* is not enough for evaluation. Overall performance as a biocontrol agent must be evaluated in greenhouse trials or using simulation models. Since greenhouse trials are time-consuming and labor intensive, development of simulation models is recommended for future work. In fact, a simulation model for describing the population interaction between *T. palmi* and *O. sauteri* on eggplants is now being developed for this purpose.

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