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Integrated Control in Field Vegetable Crops

Lutte Intégrée en Culture de Légumes

editors:

Stan Finch, Chris Hartfield & Etienne Brunel

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IOBC / WPRS

Working Group

"Integrated Control in Field Vegetable Crops"

OILB / SROP

Groupe de Travail

"Luttle Intégrée en Culture de Légumes"

PROCEEDINGS of the MEETING

COMPTES RENDUS de la RÉUNION

at / à

Chania (Crete)

6-8 October 1997

Edited by Stan Finch, Chris Hartfield & Etienne Brunel

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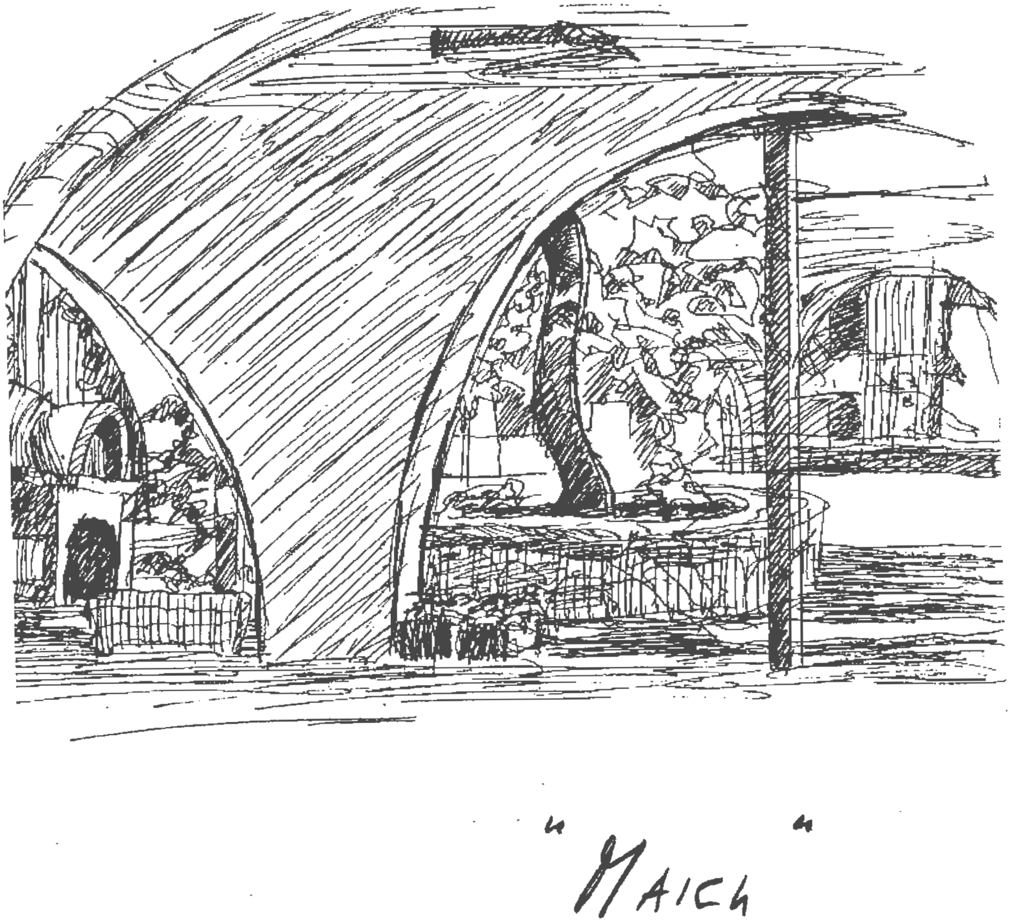

Entrance to the Mediterranean Agronomic Institute of Chania.
(Sketch by Aud Lilleengen –1997)

INTRODUCTION

The main emphasis within this Working Group has been to develop methods to reduce the amounts of insecticide used in field vegetable crops. Since the meeting in Guitté, France in 1995, there has been a considerable change in the approach of Group members, many of whom now seem to be concentrating on methods of control that can be used to supplement insecticides rather than replace them.

The venue chosen for the meeting, the Mediterranean Agronomic Institute of Chania (MAICh), and the meeting itself was appreciated greatly by all participants. I therefore thank Dionyssios Lykouressis, the local organizer, and Dionyssios Perdikis and Stelios Michelakis for all they did to make our meeting so enjoyable. I also thank most sincerely, Alkinoos Nikolaidis, the Director of MAICh, who arranged to delay the start of the new student term so that we could hold our meeting.

The thirty-five papers presented at Chania included three on pest sampling, seven on Integrated Pest Management, three on insect behaviour, nine on predators and parasitoids, five on undersowing, and eight on insecticides. The latter included both synthetic compounds and extracts of naturally-occurring compounds, such as neem.

The one outstanding topic from our earlier meeting, that of producing "Guidelines" to minimize environmental disturbance during crop protection, was addressed by both Bodil Jönsson from Sweden and Peter Esbjerg from Denmark

I was particularly happy to welcome Jeff Wyman and Brian Flood to the meeting, as their inputs concerning the current situation in the USA helped greatly to broaden and enliven the scientific discussions. I am also extremely grateful to Aud Lilleengen for allowing me to use two of the sketches she made at Chania to illustrate this Bulletin. Much of the detailed discussion between group members is done during the artistic, social and cultural outings that always form an integral part of our meetings, and so it is good to be able to highlight this aspect with an illustration.

During the meeting, Stefan Vidal was elected as the new convener, a change that has now been ratified by Council. I hope Stefan gets as much enjoyment from being convener of the meetings in the future as I did in the past.

Finally, I thank the secretaries from the Department of Entomological Sciences at HRI Wellesbourne for the marvellous job they did in re-typing the manuscripts into a standard format. I apologize for this Bulletin not being ready during 1998, but various changes within the Department have meant that five different secretaries have been involved in compiling the final document. With all the trials and tribulations in compiling this document, I now regard 5 May 1999 as a "red letter"day.

Stan Finch, Wellesbourne, 5 May 1999.

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Simulating sampling strategies for aphid and caterpillar pests of brassica crops

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Abstract: Commercial *Brassica* crops were sampled in 1996 to determine the within-crop distribution of the cabbage aphid (*Brevicoryne brassicae*) and five species of pest caterpillars (*Plutella xylostella, Pieris rapae, Pieris brassicae, Mamestra brassicae, Evergestis forficalis, Autographa gamma*). An average of only 5.6% of plants was infested with cabbage aphid, whereas 15.2% of plants were infested with caterpillars, the diamond-back moth being the predominant species. With a few exceptions, more plants were infested with pests around the edges than in the middle of the crop. Overall, similar numbers of plants were infested in the corners of fields as along the field edges. A computer program was developed in MATLAB to simulate a range of crop sampling strategies, using the information collected from commercial fields. The program can be used to test different combinations of sample size, sampling area and plant selection technique. Using the simulation program it was apparent that estimates of the true level of pest infestation became more reproducible as the number of plants sampled was increased.

Key words: Sampling strategies, *Brevicoryne brassicae, Plutella xylostella, Pieris rapae, P. brassicae, M. brassicae, Evergestis forficalis, Autographa gamma.*

Introduction

Systems of supervised control for foliar pests of *Brassica* crops have been developed in North America, Northern Europe (Ellis *et al.* 1988; Hommes *et al.,* 1988) and particularly in the Netherlands (Theunissen, 1984; 1988; 1991; Theunissen & Den Ouden, 1985). Evaluation of such systems in small plot trials in the UK (Blood Smyth *et al.*, 1992; 1994; Emmett, 1992; Paterson *et al.*, 1994), showed that the numbers of insecticide sprays applied against cabbage aphid (*Brevicoryne brassicae*) and caterpillars (*Plutella xylostella, Pieris rapae, Pieris brassicae, Mamestra brassicae, Evergestis forficalis, Autographa gamma*) could often be reduced considerably without reducing the levels of control.

Being able to rely on treatment thresholds, to make spray decisions, depends on having robust estimates of the levels of pest infestation in individual crops. Previous work in the UK (Blood Smyth *et al.*, 1992; 1994; Emmett, 1992; Paterson *et al.*, 1994) was done in small plot experiments where the numbers of plants sampled on each occasion represented a large proportion of the total plants in the plot. It would be physically impossible to sample a similar proportion of plants within a commercial crop. So when growers walk and inspect their crops, they are, of necessity, taking a very small sample, from which they estimate the size of the actual population.

The distribution of pest insects within a crop is unlikely to be uniform and pests may be aggregated in particular areas. For treatment thresholds to be used on a field-scale, growers need a robust sampling scheme with known levels of accuracy, that is both easy to use and cost-effective. The sample must be as representative as possible of the crop as a whole, or of the areas of the crop that the grower most wishes to protect. To err on the side of caution, growers may wish to sample areas of the field which are most likely to be infested and to make treatment decisions on that basis.

Over the last four years, a large number of commercial *Brassica* fields and untreated *Brassica* plots have been sampled to determine the within-crop distribution of aphid and caterpillar pests. More recently, a program has been developed in the computer package MATLAB to simulate a range of crop sampling strategies using data collected from commercial fields during 1996. Using this program it is possible to examine how factors such as infestation size, sample size and sample location influence the potential variability that occurs in any estimate made concerning the size of a pest infestation.

Materials and methods

Distribution of pests in commercial crops

Between 11 July and 23 October 1996, 20 commercial crops in South Lincolnshire were sampled intensively to determine the numbers of plants infested with aphids and caterpillars. A further crop was sampled in Bedfordshire, but only to assess the distribution of caterpillars. Suitable fields were identified by scouting at regular intervals; the aim being to sample crops with a range of levels of infestation. Fields were sampled usually prior to spraying, when pest numbers were at their highest. Only fields, identified during the preliminary scouting, that had more than 5% of plants infested with either aphids or caterpillars were selected.

Plants were sampled from nine locations within each field. These locations were determined from work done previously on the distribution of *Brassica* crop pests. The numbers and size (length in mm) of caterpillars, the numbers of winged and single wingless cabbage aphids and the numbers and size of cabbage aphid colonies on each plant were recorded. For completeness, the numbers of mummified aphids parasitized by the wasp *Diaretiella rapae* and the numbers of aphid predators (ladybirds, hover fly larvae, lacewings) were also recorded.

Although, experimentally it is important to record the numbers of insects on each plant, to obtain an estimate of the overall size of the pest population, practically it is easier to base crop walking on the presence or absence of aphids or caterpillars on each plant and to make decisions based on the proportion of plants infested. In this paper, infestation levels will be described only in terms of the proportion of plants infested.

A total of 550 plants were sampled in each field. Samples were taken from each area as follows:

Edges - A total of 50 plants were sampled from along each edge of the crop. Ten plants were sampled from each of rows 6-10 from the outside edge. Within a row, the plants sampled were 5 paces apart and adjacent rows were staggered slightly to avoid sampling adjacent plants in neighbouring rows.

Corners - Fifty plants were sampled from each corner of each field. Five plants were sampled from each of rows 6-15 from the outside edges. Within a row the sampled plants were 3 paces apart and the rows were staggered to avoid sampling adjacent plants in neighbouring rows. The sampling plan was adapted for those corners that had not been planted completely.

Middle - A total of 150 plants were sampled from the middle of each crop. Ten plants were sampled from each of 15 alternate rows in the centre of the field. Within a row, the plants sampled were 5 paces apart and the rows were also staggered.

Field information - A plan was drawn of each field to record its approximate dimensions and orientation (N, S, E, W). The approximate height of the field boundaries was also recorded. The crops sampled were either cauliflower, calabrese or Brussels sprouts. A few fields were planted with both calabrese and cauliflower.

Data analysis - The data for each field were entered onto spreadsheets and the numbers of plants infested with aphids, with each species of caterpillar, or with any species of caterpillar, were calculated.

Simulation of crop sampling strategies

A program was developed in the computer package MATLAB to simulate a range of crop sampling strategies using the data set collected from commercial fields. Options which can be selected within the program include:

1) Crop - Currently the 21 data sets collected in 1996 are available, covering a range of ***Brassica*** crops sampled at different times of year.

2) Areas of the field to be sampled - Data are available on pest infestation levels in the four corners of the field, along the four edges of the field, and from the middle of the field. Any combination of areas can be selected, and the number of edges or corners to be sampled must also be chosen where appropriate. At present, where multiple corners or edges are selected they are chosen at random within each simulation run. In a future version of the program it will be possible to select specific corners or edges.

3) Sample size - Limits on the possible sample size are set according to the areas selected. Having selected the overall sample size, it is possible to sample equally from each of the selected areas or according to a range of pre-defined ratios (e.g. two thirds of the samples from one area and one third from another area).

4) How plants are chosen within the sampling areas - Plants can either be sampled completely at random, along pre-defined transects, or from clumps. The same approach is used in each of the sampling areas.

5) Number of replicate simulations - A default setting of 100 is provided - the more simulations the longer it takes to produce results, but the more accurate the picture of potential variability. The results of the repeated runs for each sampling strategy are summarised graphically and numerically to demonstrate the potential variability in the estimate of the level of pest infestation. The benefits of selecting a suitable sampling strategy can be seen by running simulations of a number of different sampling strategies.

Results

A mean of 5.6% of plants were infested with cabbage aphid in the 20 intensively sampled (11,000 plant sampled) fields. No aphids were found in three of the crops sampled. Although lower numbers of aphids would be expected in commercial crops than in untreated areas of crop, the overall level of infestation in south Lincolnshire during 1996 was extremely low. A mean of 15.2% of plants was infested with caterpillars in the 21 intensively sampled (11,500 plants) fields. Caterpillars were found in all of the crops sampled and *Plutella xylostella* was by far the most numerous species.

Distribution of pests in commercial crops

On average, plants sampled at either the edges or the corners of the field were infested equally with aphids (6.1 and 6.9% respectively) but were twice as infested as plants in the middle of the field (3.3%) (Figure 1). Similarly, plants sampled at either the edges or the corners of the field were also infested equally with caterpillars (16.9 and 16.4% respectively) but were more infested than plants in the middle of the field (11.4%) (Figure 1).

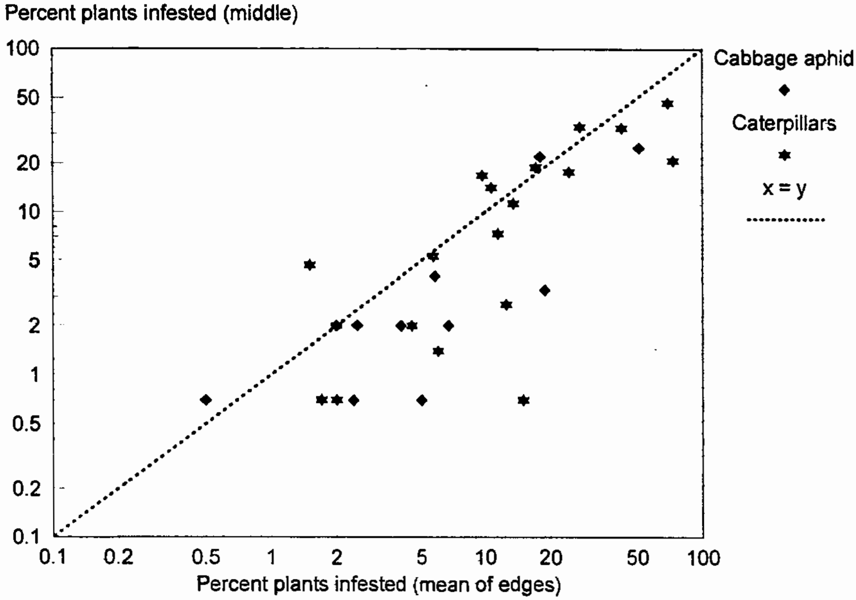

Figure 1. The relationship between the percentage of plants infested in the middle and the mean percentage of plants infested on the edges of commercial crops sampled during 1996.

There were often differences in the percentage of plants infested, between the edges and the corners of an individual field. For example, in one field, planted with cauliflower, 12% of plants on Edge 3 were infested with caterpillars and 0% on Edges 1 and 4. In the same field, 8% of plants on Edge 2 were infested with aphids and 32% on Edge 4. In other crops, aphids and caterpillars were distributed more evenly.

The orientation (N, S, E, W) of the most heavily infested edge(s) in each field was determined (fields with two-equally infested edges were scored as 0.5 for each edge and three equally infested edges as 0.3 for each edge). No pronounced trend was evident, although, if anything, more caterpillars were found along the NW/SE axis and more aphids along the SW/NE axis. Similarly, the heights of the field boundaries were compared with the percentage of plants infested and again no pronounced trends were evident. However, most of the field boundaries were low and few of the fields were bounded consistently by very tall hedges or trees; which may be important factors in determining the distribution of pests in more sheltered fields.

Simulation of crop sampling strategies

The simulation program allows an infinite number of sampling strategies to be tested and can be used to indicate trends associated with, for example, changes in sample size or in sampling area. Figure 2 shows the graphical output from 100 repeated simulations of one such sampling strategy for the diamond-back moth, where only one edge of the selected crop (cauliflower sampled on 13 August 1996) was examined and 10 plants were selected along a transect. The mean infestation level was 14.1% and the estimates of the level of infestation ranged from 0-50%.

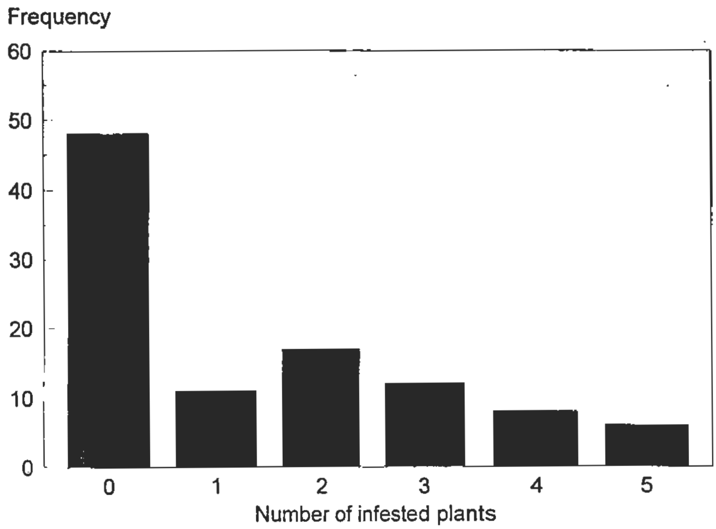

Figure 2. Output from 100 repeated simulations of a sampling strategy, where only one edge of a cauliflower crop (sampled on 13 august 1996) was examined and 10 plants were selected along a transect (print of simulation run is in Appendix 1). The mean infestation level was 14.1% and the estimated infestation levels ranged from 0 to 50%.

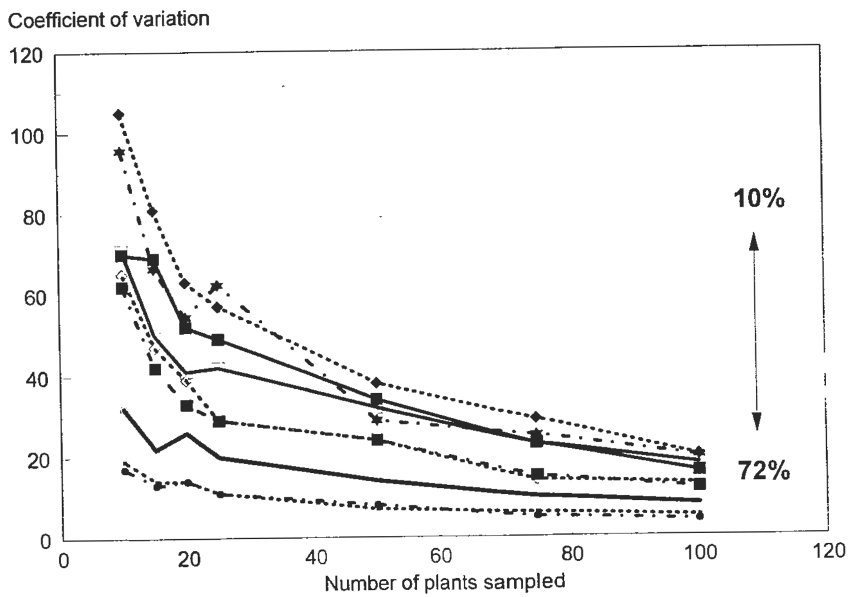

Figure 3. The effect of sample size on the coefficient of variation (CV) when repeated (100) simulations were made of a sampling strategy that included all four edges of the crop.

Figure 3 shows the effect of sample size on the coefficient of variation (CV) when repeated (100) simulations were made of a sampling strategy for the diamond-back moth that included all four edges of the crop. The graph shows data from 7 fields with mean infestation levels ranging from 10 to 72%. As the sample size increased, repeated estimates of the percent plants infested became more reproducible and the CV was reduced. The CV was also affected considerably by the level of the overall caterpillar infestation within the crop. When caterpillar numbers were high, the sampling strategy was reproducible (low CV) even at quite small sample sizes.

Choice of sampling area(s) will also determine the variability of the estimate of the population. If samples are taken only from the middle of the crop then this will on average indicate a level of infestation for caterpillars which is approximately 70% of that at the field edge and for aphids only 50%. If only one of the edges or corners is sampled then this estimate may not necessarily indicate the worst scenario. In general the CV was reduced, and estimates became more reproducible, as more edges or corners of the crop were sampled.

Discussion

On average, similar numbers of cabbage aphids and caterpillars were found both in the corners of the field and along the field edges. However, more plants were infested in the edges and corners of the field than in the middle of the crop. If growers are looking for the 'worst scenario' then they should concentrate on the edges and corners of the field rather than the middle of the crop. In some fields, certain edges or corners were more heavily infested than others. However, at this stage of the project, pest distribution could not be related directly either to the orientation (N, S, E, W) of the field or to the height of field boundaries. A better estimate of the size of the pest infestation in each crop was obtained by looking at several edges and/or corners rather than by concentrating on a single area. Thus, to provide the best measure of the 'worst scenario', growers should look at more than one of these areas of the field.

Estimates of the true level of infestation became more reproducible as the number of plants sampled was increased. Unless pest numbers were very high, samples of less than about 25 plants gave very variable estimates of the level of aphid infestation. If growers look at a very small number of plants, they may obtain a very poor estimate of the overall level of infestation, particularly if aphid and caterpillar numbers are low. At very low levels of infestation, growers may have to look at a relatively large number of plants to detect pest presence. The effects of sample size and infestation level on the reproducibility of an estimate indicate that in practical situations it will be more appropriate and cost-effective to use a sequential sampling system rather than fixed-size samples. By using a sequential sampling system, crop walking will be terminated once sufficient information has been obtained to make a reliable decision.

The statistical techniques described in this paper can be used to indicate the level of confidence growers can have in any particular sampling strategy. Future developments of the program will incorporate a decision-making process based on the use of treatment thresholds (Blood Smyth *et al., 1994)* and the use of a sequential sampling approach.

Résumé

Simulation de stratégies d'échantillonnage pour les ravageurs pucerons et chenilles en cultures de Brassica.

Les cultures commerciales de Brassica ont été échantillonnées en 1996 pour déterminer la distribution, à l'intérieur des champs, du puceron cendré du chou (*Brevicoryne brassicae*) et de six espèces de chenilles (*Plutella xylostella, Pieris rapae, P. brassicae, Mamestra brassicae, Evergestis*

forficalis, Autographa gamma). En moyenne 5.6% seulement de plantes sont infestées par les pucerons, 15.2% infestées par des chenilles, la teigne étant l'espèce dominante. A quelques exceptions près, la plus part des plantes infestées sont disposées plus près des bordures qu'au centre des parcelles. Partout, des quantités similaires de plantes infestées sont trouvés dans les coins des champs comme le long des bordures. Un programme informatique (logiciel) est développé en MATLAB pour simuler une série de stratégies d'échantillonnage, à partir des informations collectées dans ces champs. Le programme peut être utilisé pour différentes combinaisons de taille de champ, de surface échantillonnée et de technique de sélection des plantes. L'utilisation du programme de simulation montre que l'estimation du véritable niveau d'infestation des ravageurs devient très reproductible lorsque le nombre de plantes échantillonnées augmente.

Acknowledgements

This work has formed part of LINK Project P132 and HDC Projects FV 163 and 194. We are grateful particularly to Sally Minns of HRI Kirton and Jennie Blood Smyth of ADAS Arthur Rickwood for collecting data, and to the Old Leake Grower's Association and Bedfordshire Growers for allowing us to sample their crops.

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A new approach to characterising within-field pest distributions using mealy cabbage aphid (*Brevicoryne brassicae*) on Brussels sprouts as an example

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Abstract: A novel methodology for developing simulations of the within-field distribution of *Brevicoryne brassicae* on Brussels sprouts is described. The simulation process is based on field data collected at different spatial scales, and takes into account both the numeric properties of *B. brassicae* counts on individual plants and the spatial distribution of infested plants. The aim of this work is to develop a tool for validating different field-sampling plans for pest management decision-making in 'supervised' control systems, without the need for extensive field validation. Preliminary data analyses are presented and discussed within the context of the overall project objectives.

Key words: Sampling precision, within-field sampling, *Brevicoryne brassicae*

Introduction

The key to the commercial adoption of 'supervised' control systems is the development of a sampling system that reflects accurately the pest situation in the field with the minimum time input. Recent work on supervised control of brassica pests (including *B. brassicae*) in the UK (Blood Smyth *et al.*, 1992; Paterson *et al.*, 1994) has concentrated on evaluating sequential sampling systems based on the Wald sequential probability ratio (Lynn & Mead, 1994). Similar work examined the use of simpler systematic sampling plans (Emmett, 1994). These systems have not, as yet, been extensively taken up by the industry, largely because of the labour input required. Moreover, the validation of such sampling schemes requires extensive field work. This paper summarises work done to generate realistic simulations of within-field *B. brassicae* distributions that allow both for the variance-heterogeneity of counts and their spatial arrangement. The aim is to use these simulations to develop and evaluate sampling plans for making field-scale decisions on aphid control without the need for extensive field work.

Materials and methods

The process involved in generating the simulations requires several phases. These are summarised as follows:

1. Field data collection.
2. Data analysis - numeric (variance-mean and incidence-mean) and spatial analyses.
3. Simulation of aphid counts at a pre-set level of incidence.

4. Overlay of counts on an artificial 'field' of plants, and arrangement of those counts according to spatial analyses.
5. Integration of simulations into a Geographic Information System (GIS) to allow spatial querying and analysis of the data.

Field data collection was done in two 1 ha blocks in four commercial Brussels sprout fields in 1996, including one site (at ADAS Arthur Rickwood) that remained completely untreated throughout the season (a further four sites were sampled in 1997 but the results are not reported here). Aphid counts were made initially at weekly, and then fortnightly intervals through the season using a 'nested' sampling grid that allowed data to be gathered at different spatial scales. These ranged from the 'small scale' (plant-to-plant) through the 'medium scale' (sampling areas <30 m apart) to the 'large scale' (sampling areas >30 m apart). Full details of the experimental design for field data collection, and the detail of the approach to the analysis of the numeric properties of the data have been described elsewhere (Parker *et al.*, 1997).

The outcome of the numeric analysis is a series of regression equations describing the variance-mean and incidence-mean relationships in the count data at (i) different spatial scales, (ii) between blocks within a site, and (iii) between sites. These relationships are used to generate the simulated count data in a process (Perry *et al.*, in preparation) that scales up the original number of aphid count observations 64 times.

A range of spatial analyses were done on the data to determine if aphid distributions were non-random. The principal statistical tool used in this process was SADIE (Spatial Analysis by Distances IndicEs), described fully by Perry (1995).

Once count simulations had been analysed and arranged, the data were loaded into a GIS system (ArcView version 3.0). This includes a full range of spatial and logical query tools which can be customised and automated to allow rapid repeated analysis of the same sampling plan on different simulations.

Results and discussion

B. brassicae populations were low throughout the U.K. in 1996, and only very low infestations were recorded at insecticide-treated commercial sites. At the untreated site (Arthur Rickwood), a steady increase in pest incidence occurred between mid-July and October reaching a peak of 97% plants infested by the end of November. Numbers of aphid per plant also generally increased through the season, reaching a peak of 586 per plant by the time peak incidence occurred at the end of November.

Results from the numeric and spatial analyses presented below are based on data from the Arthur Rickwood site only, and are presented in summary form. Full details are given in Perry *et al.* (in preparation).

Numeric analyses

At the small (plant-to-plant) scale, estimated slopes and intercepts of the variance-mean regressions changed systematically through the season when lines were fitted to data from each assessment date separately (Table 1). This indicates significant changes in these relationships with time which need to be accounted for when generating simulations.

Similarly, incidence-mean regression parameters also changed systematically over time. For a given aphid density, more plants were infested as the season progressed, although for that density there were, on average, fewer aphids per plant at later assessment dates.

Table 1. Slope and intercept values for variance-mean regressions on aphid count data on selected assessment dates through the season.

Sample date	Intercept	Slope (b)
23-Jul	0.581	2.000
07-Aug	0.494	1.832
01-Oct	-0.955	2.406
20-Nov	-0.413	2.216

Spatial analyses

The SADIE analytical method uses the spatial component of a data set to measure the degree of aggregation, or otherwise, of the variable in question. One statistic generated by SADIE is I_a, the aggregation index. Extensive analysis of the data set taking different scales and dates separately or using pooled data, indicated that there was no consistent aggregation in the distribution of the aphids at any time during the season. In summary, median values for I_a across all assessment dates at all scales did not significantly differ from 1 (Table 2). This indicates that aphid distributions were essentially random.

Table 2. Median values for the aggregation index I_a at the small, medium and large sampling scales (see above for definitions of small, medium and large scale).

Scale	Median Index (I_a)
Small	1.03
Medium	1.00
Large	0.99

The conclusion that aphid distributions were essentially random was supported by a range of other statistical tests, including analysis of the spatial association between distributions on successive sample dates, population trends across sample areas, and the apparent lack of edge effects at start of colonization. However, other work (Collier, this volume) has shown a marked edge effect in *B. brassicae* distributions, particularly where the edge of the field is sheltered, and subsequent re-analysis of our data did indicate a slight edge effect on the first few plants at the very edge of the crop. Work is currently in hand to ensure that edge effects can be incorporated into the simulation process.

As well as the strong suggestion that aphid distributions beyond the edge of the field were randomly distributed, there was consistent evidence to suggest that once a plant was infested it remained infested (although the population on individual plants could increase and decrease markedly over time). There were also good indications that heavily infested plants were rarely surrounded by other infested plants, suggesting that little inter-plant movement by apterous aphids occurred.

Simulation generation

Using the variance-mean and incidence means relationships, trial simulations of aphid count data with an incidence level set at 10% (a nominal threshold for treatment for *B. brassicae*, Paterson *et al.*, 1994) were generated and their location randomly assigned to a 'field' of 8000 plants. This process can be repeated many times, generating aphid spatial distributions which are physically different, but which all have the same underlying statistical definition of aphid numbers and incidence based on field observation. An example of part of one of these simulations is shown in Figure 1.

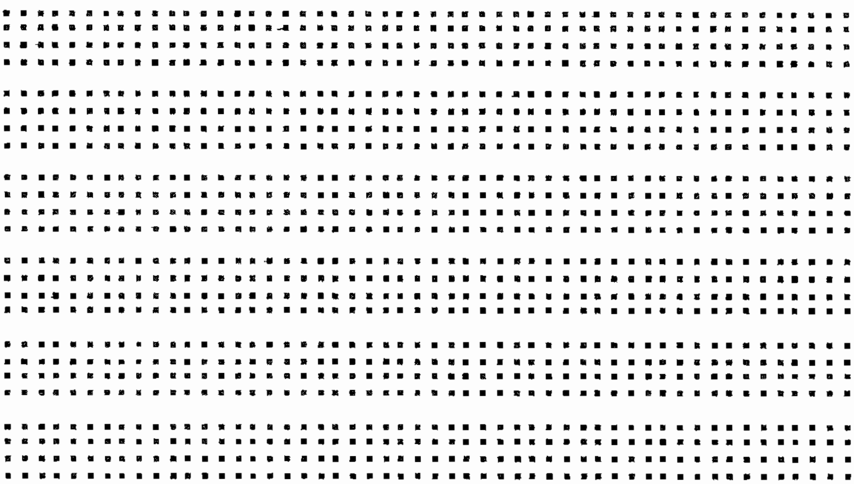

Figure 1. Part of the artificial 'field' of 8000 plants. Each dot represents a plant, and the number of aphids present on that plant is represented by the colour of the dot.

Conclusions

With these simulations, it is possible to test sampling plans against a 'known' overall infestations, something which hitherto has not been possible with field-based assessments as the time involved in sampling 8000 plants in the field would be completely prohibitive. In addition, the incidence level can be set at any desired level, allowing extensive investigation of the impact of different sampling strategies at different levels of infestation at a fraction of the time required for field-based work.

The main limitation of these simulations is ensuring that they are sufficiently representative of the range of aphid distributions encountered in the field to allow valid conclusions to be drawn about sampling strategies. Field data collected in 1997 support the broad findings of the initial 1996 analyses. As the simulations are entirely founded on field observation, and provided the assumptions that underlie their use are made explicit, it is reasonable to suggest that they are sufficiently robust to provide a fair test of competing sampling strategies.

Résumé

Une nouvelle approche pour caractériser la distribution des ravageurs à l'intérieur du champ en utilisant comme exemple le puceron cendré du chou (*Brevicoryne brassicae*) sur chou de Bruxelles

Une nouvelle méthodologie pour les simulations mettant en valeur la distribution au champ de *Brevicoryne brassicae* en culture de chou de Bruxelles est décrite. Le processus de simulation est basé sur des données collectées au champ à différentes échelles et prenant en compte à la fois la valeur numérique des comptages de *B. brassicae* observés sur des plantes individuelles et sur la distribution spatiale des plantes infestées. Le but de ce travail et de développer un outil de lutte intégrée, permettant à partir de l'échantillonnage aux champs, une prise de décision de lutte sans utiliser des observations en champ en grandeur nature. Les analyses préliminaires des données sont présentées et discutées dans le contexte des objectifs du projet global.

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Use of a geographical information system (GIS) for forecasting the activities of carrot fly and cabbage root fly

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Abstract: Activities of the carrot fly, *Psila rosae*, and the cabbage root fly, *Delia brassicae*, were forecast using meteorological data obtained from the Finnish Meteorological Institute. Air temperatures at 35 automatic weather stations were analysed using GIS (geographical information system) tools, and the predicted activities of the pests were displayed as thematic maps on the AGRONET (http://www.mtt.fi/ks/ajankohtaista). The forecasts were validated by means of pest monitoring data stored in the database of the Agricultural Research Centre of Finland (MTT). In the summer of 1997, the flight of overwintered adults of the bivoltine type of *P. rosae* (southern Finland) started during the 23rd week of the calendar year and peaked during calendar week 24. Preliminary validation of the forecasts suggested that the threshold temperature sum (effective temperature sum, ETS) should be 255 DD_5 for the start of the flight and 355 DD_5 for the peak. The forecast concerning the second flight was in line with the monitoring data. The flight started when 800 DD_5 had accumulated and peaked at 860 DD_5. Forecasts of the activity of the univoltine type (northern Finland) of the carrot fly were precise enough to indicate to farmers when they should start monitoring or applying control measures in individual fields. In practice, the same ETS values can be used for predicting the activities of both types of the carrot fly. The forecasts concerning the first flight of the cabbage root fly, *D. radicum*, coincided relatively well with the first egg-laying period. In the forecast, 80 DD_5 was used as the threshold ETS value for the start of the flight and 150 DD_5 for the peak. Regarding the second flight, the forecast was about two weeks early compared with the monitoring data. The preliminary threshold ETS values (600 DD_5 for the start and 750 DD_5 for the peak) should be changed after the final analysis of the monitoring data. The main problem in forecasting cabbage fly activity in Finland is the occurrence of *Delia floralis*. The flight activity of *D. floralis* peaks normally between the two peak of *D. radicum*. In many regions in Finland, both species may occur in the same fields. GIS was found to be a powerful tool for making and presenting forecasts and for analysing monitoring data. AGRONET/internet services provided a rapid and easy means of delivering the information to farmers and extension services. GIS also has the potential to produce more sophisticated simulation models for forecasting pest activity, provided relevant weather data are available at a reasonable price.

Key words: GIS, *Psila rosae*, *Delia radicum*, day degrees

Introduction

Integrated pest management (IPM) is an important prerequisite for sustainable production of horticultural and arable crops in Finland. IPM is characterised by (a) combination of cultural, biological and chemical control methods, (b) minimised/optimised use of pesticides, (c) effective use of local resources and (d) maintenance of ecologically and economically sustainable farms and production chains. On farms, monitoring of pests at the level of the individual field yields the most important information required for planning of pest control and implementation of IPM strategies. Forecasting and warning systems also play an essential role in decision-making.

The Agricultural Research Centre of Finland (MTT) has introduced a forecasting and warning service to meet the needs of IPM and to allow an effective flow of information between researchers, advisers and farmers. The systems use modern information technology such as geographical information systems (GIS) and AGRONET/INTERNET services. Although the service may provide suggestions on control methods, the farmer should make the final decision about his/her need of pest control and the choice of control methods.

Materials and methods

The forecasting systems are based on research work at MTT and an analysis of monitoring data which have indicated a relationship between pest activity and effective temperature sum (ETS). For predicting the activity of the carrot fly (*Psila rosae*), the initial threshold ETS values (calculated from air temperatures exceeding 5°C) were:

- 260 degree days (DD_5) for the start of the flight of overwintered adults
- 360 DD_5 for the peak of the first flight
- 560 DD_5 for the end of the first flight
- 800 DD_5 for the end of the second flight
- 860 DD_5 for the peak of the second flight
- 960 DD_5 for the end of the second flight

For predicting the activity of the cabbage root fly (*Delia radicum*), the initial threshold ETS values were:

- 80 DD_5 for the start of the flight of overwintered adults
- 150 DD_5 for the peak of the first flight
- 250 DD_5 for the end of the first flight
- 600 DD_5 for the start of the second flight
- 750 DD_5 for the peak of the second flight
- 1100 DD_5 for the end of the second flight

Activities of the carrot fly and the cabbage fly were forecast on the basis of meteorological data provided by the Finnish Meteorological Institute (FMI). The data were received once a day from 35 automatic meteorological stations throughout Finland (Figure 1). ETS was calculated for each station from the daily minimum and maximum temperatures $[(T_{min} + T_{max})/2 - 5°]$. ETS values of the stations were then interpolated for every grid point ($4km^2$) on the mapping system by means of ARC/Info^{TM} GIS software using Arc Macro Language (AML) scripts. The final results were transformed into transparent polygon coverage and visualised using ARC/Info^{TM} software. Once the polygon coverage was complete, the batch program transferred the polygons to the Internet Map Server which converted the information into a form accessible to Web Browsers. The Internet Map Server techniques used were developed by the Finnish National Land Survey (NLS) and MTT. The Internet Map Server was located at NLS (Widbom & Lindholm, 1997). The current stage and predicted activity of the pests were displayed as thematic maps on the AGRONET site (http://www.mtt.fi/ksl/ajankohtaista/porennus.html and http:/www.mtt.fi/ksl/akamlpjtaosta/ kaaennus.html). Daily forecasts were updated every date at 6 p.m., and the forecast for the

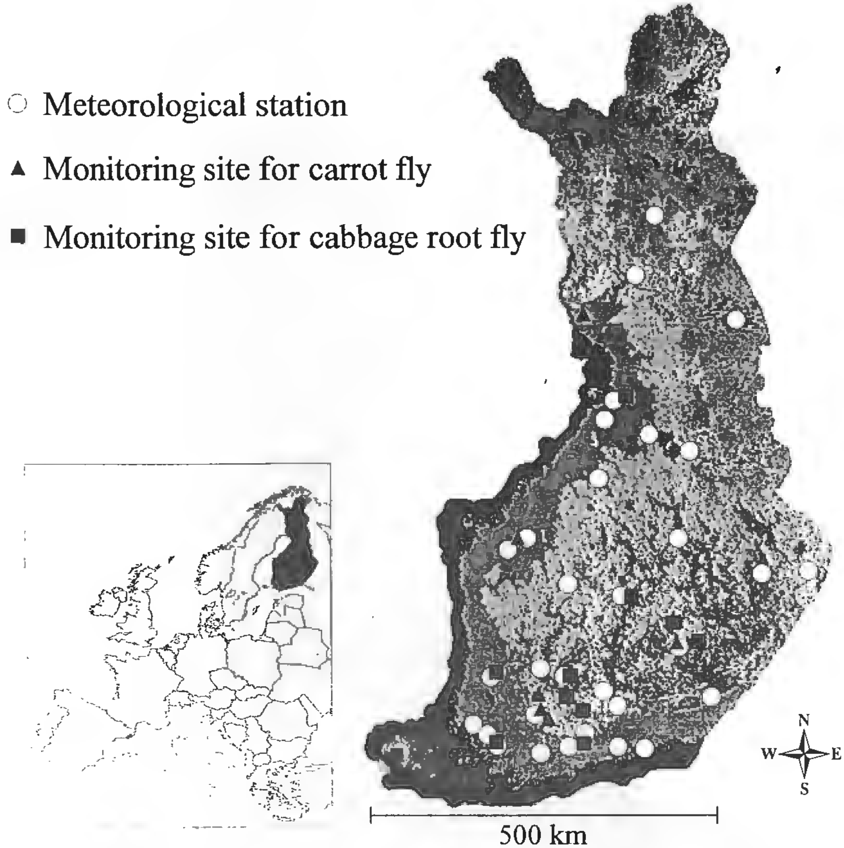

Figure 1. Locations of the meteorological stations and monitoring sites used for carrot fly and cabbage root fly.

following week was updated every Thursday. The ETS values for "next week" were calculated using ETS values of "today" and the long-term (30-years) meteorological data from FMI.

The pest forecasts were validated by monitoring data stored in the MTT database and analysed using GIS tools. The monitoring data were obtained from research stations, regional extension services and some pilot farmers. Occurrences of the pests were also shown as graphs on the AGRONET site.

Results

Carrot fly activity

The predicted time for the start of the first flight of *P. rosae* (bivoltine type) was the 24th week of the calendar year and for the first peak the 26th calendar week (Figure 2). In southern

Finland (Taivassalo), the first flies were trapped during calendar week 23 (Figure 3) and the catch of the flies peaked during calendar week 24. In northern Finland, the flight of *P. rosae* (univoltine type) was predicted to start in calendar week 26 and to peak in calendar week 28. Catches from yellow sticky traps in Tornio confirmed the prediction exactly.

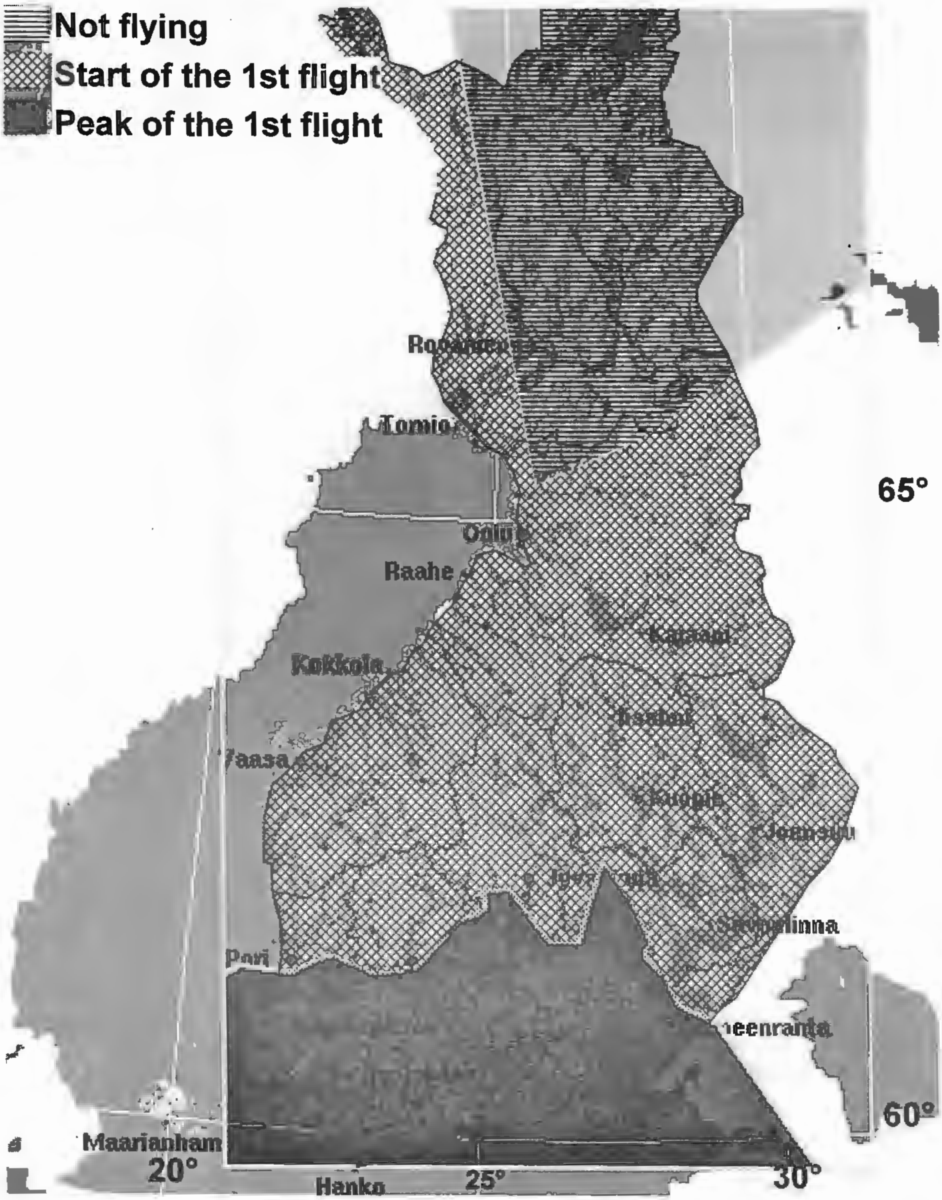

Figure 2. Pest forecast of the activity of carrot fly in calendar week 26 (27/6/97).

The predicted time for the start and peak of the second flight of *P. rosae* in southern Finland were calendar weeks 30 and 32, respectively (Figure 4). Catches from yellow sticky traps in Taivassalo showed that the predictions for the start and peak were correct (Figure 3).

Cabbage root fly activity

The predicted times for the start and peak of the first flight in southern Finland were calendar weeks 21 and 24, respectively (Figure 5). Soil samples indicated that the first eggs were laid during calendar week 21 (Figure 6) and numbers of the eggs peaked during calendar week 25. The predicted time for the start of the second flight was calendar week 29 and for the peak fly activity was calendar week 31 (Figure 7) in southern Finland. According to the monitoring data, the second egg-laying period started during calendar week 30 (Figure 6) and peak numbers of eggs were recorded during calendar week 33. After the peak, small numbers of eggs were laid each week until harvest.

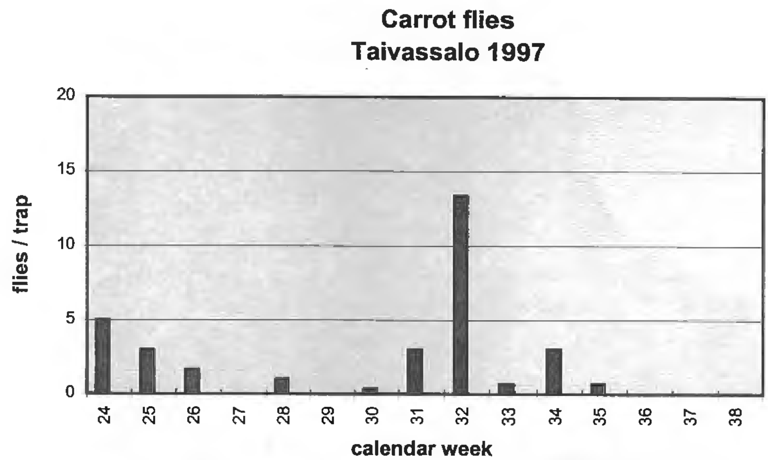

Figure 3. Numbers of carrot flies caught weekly on yellow sticky traps in Taivassalo, Southern Finland.

Discussion

Preliminary validation showed that the forecasts predicted well the activity of the carrot fly. Differences between the two types of the carrot fly were small, and in practice the same ETS values can be used for both: 255 DD_5 for the start and 355 DD_5 for the peak of the first flight. For the second flight, the corresponding ETS values were 800 DD_5 and 860 DD_5. The relationship between accumulated temperature and the activity of the overwintered generation proved to be very similar in Finland and in southern Ontario (Stevenson 1989). In contrast, the start of the second period of fly activity required a much lower heat accumulation in Finland (800 DD_5) than in Ontario (1142 DD_5). Adaptation of *P. rosae* to the short growing

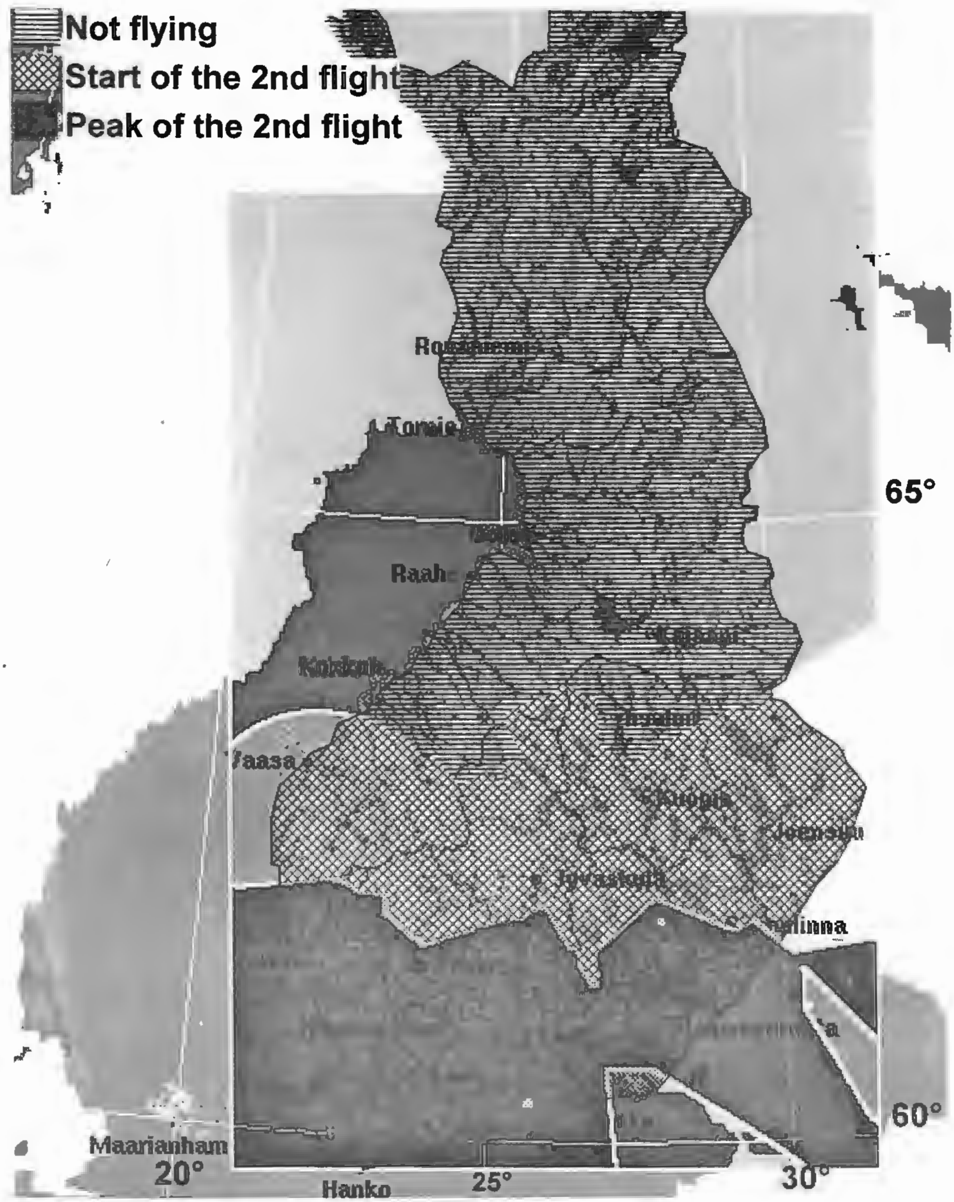

Figure 4. Pest forecast of the activity of carrot fly in calendar week 32 (4/8/97).

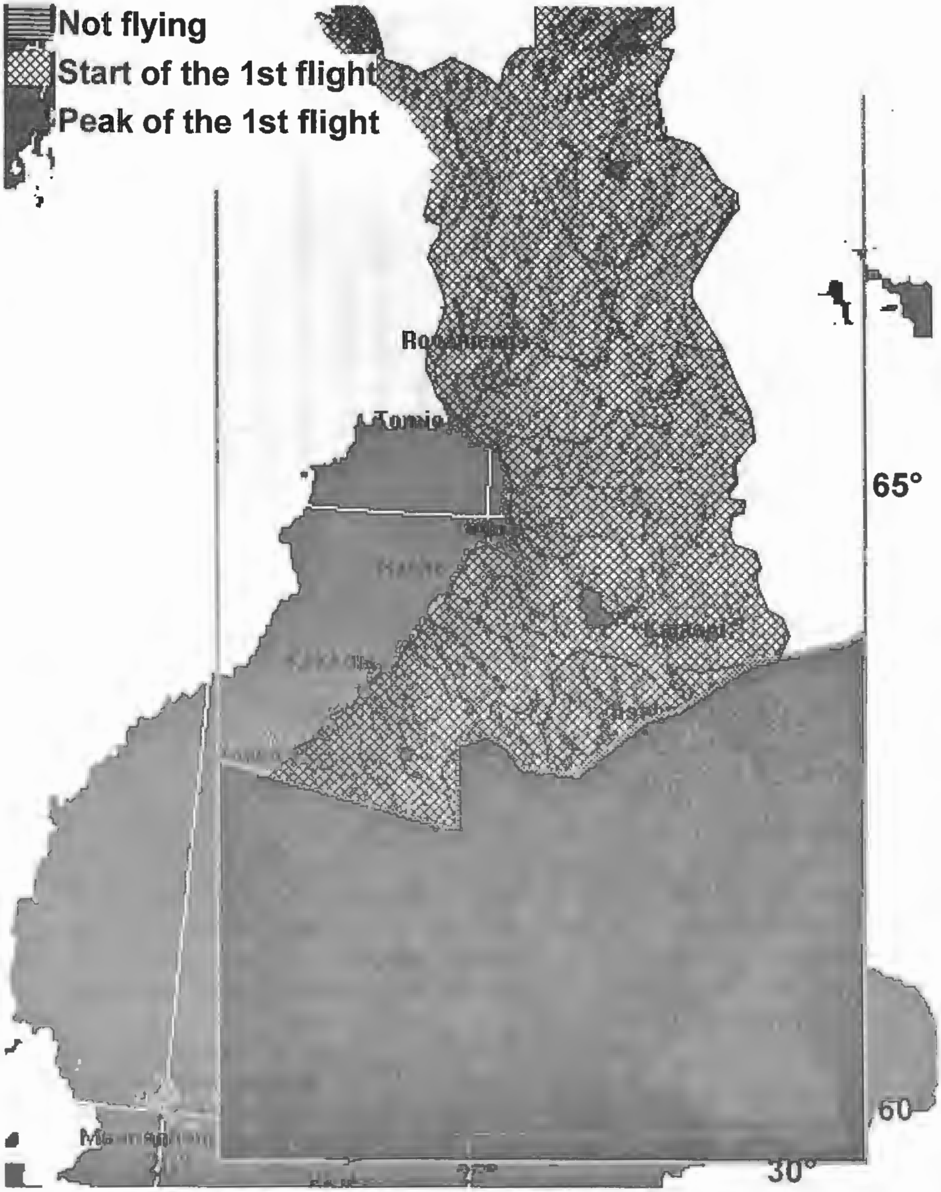

Figure 5. Pest forecast of the activity of cabbage root fly in calendar week 24 (11/6/97).

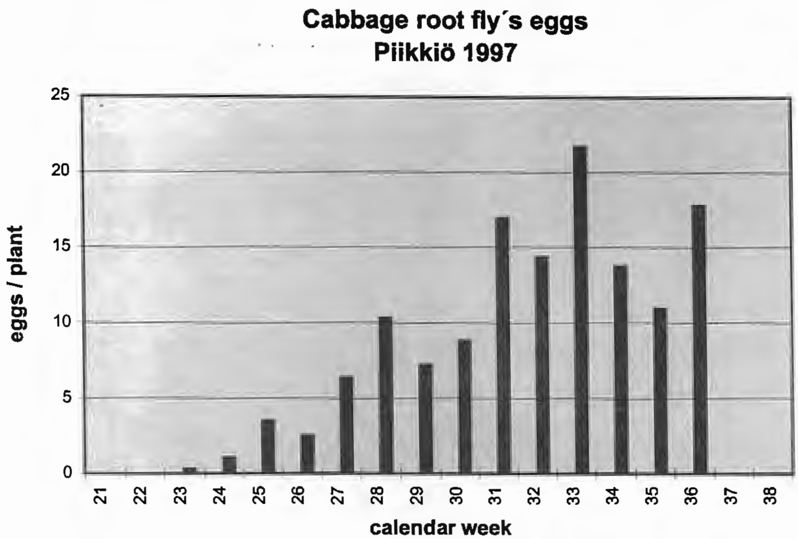

Figure 6. Numbers of cabbage root fly eggs recovered each week from soil samples collected at Piikkiö, Southern Finland.

season in Finland may be one reason for the observed difference in activity.

The forecast concerning the first flight of *D. radicum* (ETS values of 80 DD_5 for start and 150 DD_5 for peak) was reasonably good. For the second period of the activity, however, higher values than the predicted 600 DD_5 for the start and 750 DD_5 for the peak, should be used in the future. *D. radicum* requires lower ETS values for activity than do more southern populations or a population studied in Norway (Collier & Finch 1983, Johanssen & Hals 1990). One way to produce more accurate ETS values is to increase the monitoring data from different parts of the country and to link these data to weather data. Nevertheless, the occurrence of two *Delia* species makes the prediction rather complicated, necessitating two different, species-specific predictions.

Experiences of the use of GIS as a "forecasting tool" were very positive. Likewise the AGRONET (the internet service run by MTT) proved to be a rapid and relatively easy way to deliver "on-line" information to farmers and extension services. Recently, a collaborative project has been launched to enable the use of GIS and internet systems for forecasting pests and diseases in all of the Nordic countries. The aim is produce thematic maps for the whole area and to develop a validation system based on standard monitoring practices and data management.

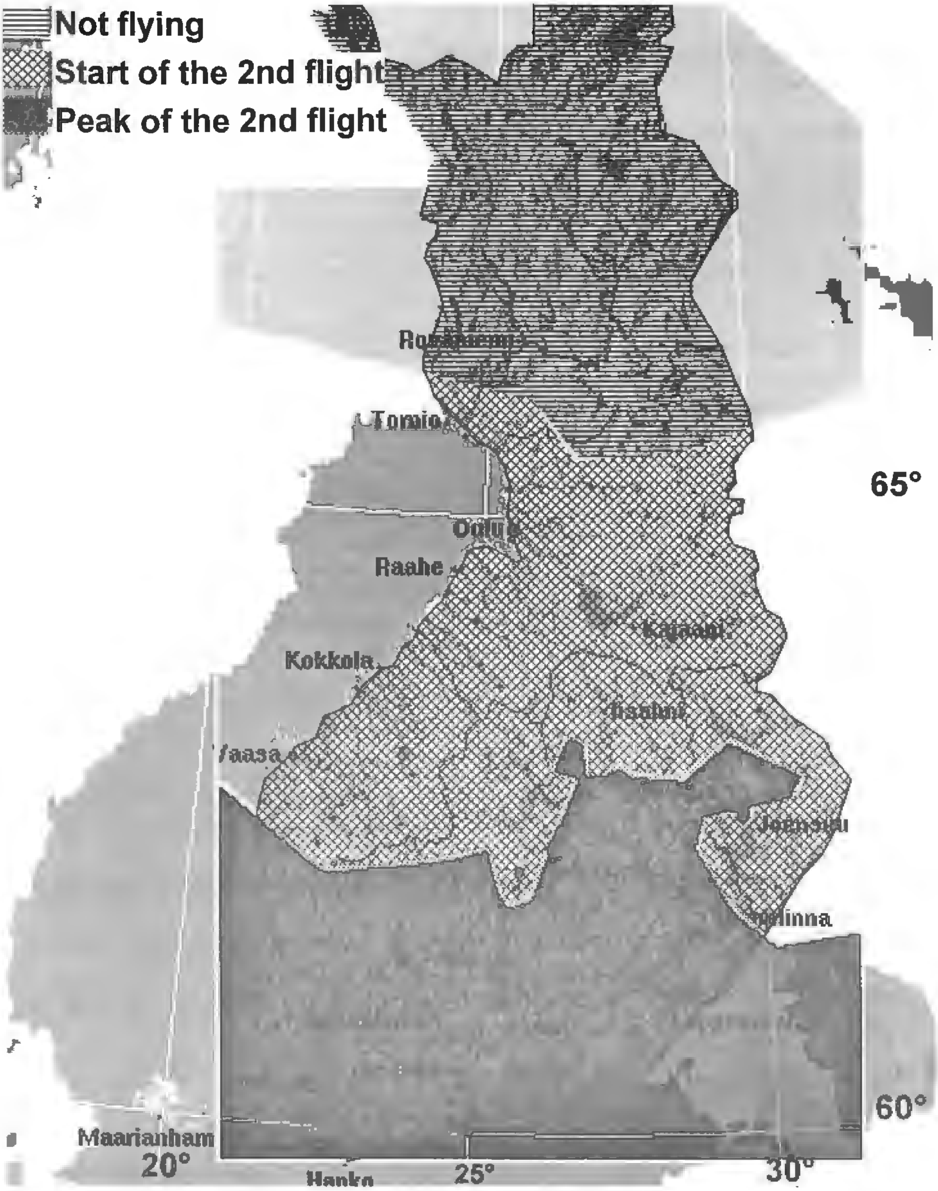

Figure 7. Pest forecast of the activity of cabbage root fly in calendar week 31 (29/7/97).

Résumé

Utilisation d'un système d'information géographique (SIG) pour prédire les activités de la mouche de la carotte et de la mouche du chou.

Les activités de la mouche de la carotte, *Psila rosae*, et de la mouche du chou, *Delia radicum*, sont calculées en utilisant des données météorologiques obtenues de l'Institut météorologique Finnois. Les températures de l'air de 35 stations automatiques sont analysées en utilisant l'outil du SIG (système d'information géographique), et les activités prédites des ravageurs sont projetées sur les cartes thématique de AGRONET (http://www.mtt.fi/ks/ajankohtaisa). Les prévisions sont validées par les moyennes des données de surveillance des ravageurs stockées dans la banque de données du Centre de Recherche de l'Agriculture de Finlande (MTT). En été 1997, le vol des adultes issus des pupes hivernantes de *P. rosae* de type bivoltin (du Sud de la Finlande) commence au cours de la 23eme semaine du calendrier de l'année et atteint son pic la 24eme semaine. La validation préliminaire de la prévision suggère que la somme des températures seuils (somme des températures efficaces, ETS) pourrait être de 255 degrés jours (DD) pour le début du vol et de 355 DD pour le pic. La prévision concernant le deuxième vol est en accord avec les données de surveillance. Le vol commence à 800 DD et atteint pour le pic 860 DD. Les prévisions concernant le premier vol de la mouche du chou, *D. radicum*, coïncident relativement bien avec la première période de ponte. Dans la prévision, on utilisait 80 DD comme seuil ETS pour le début du vol et 150 DD pour le pic. Par rapport au deuxième la prévision indiquait une avance de deux semaines par rapport aux données de surveillance. Les valeurs seuils ETS préliminaires (600 DD pour le début et 750 DD pour le pic) seront modifié en conséquence. Le GIS se révèle être un outil puissant pour réaliser et présenter les prévisions et pour analyser les données de surveillance. Les services d'AGRONET/internet fournissent les moyennes facilement et rapidement et permettent la diffusion de l'information aux fermiers et aux services du développement.

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Integrated Pest Management

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Strategies for the control of aphid pests of lettuce

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Abstract: In the UK, the foliage of outdoor lettuce crops is infested by three species of aphid (*Nasonovia ribisnigri, Myzus persicae, Macrosiphum euphorbiae*) whilst the roots are infested by the lettuce root aphid (*Pemphigus bursarius*). This paper describes the phenology of each aphid species, using monitoring data collected at several sites over three years. This information is being used to develop and refine temperature-based forecasts of aphid phenology. The phenological data have shown several periods during the growing season when the risk of infestation by foliage or root-feeding aphids changes. Hence, there are opportunities to use forecasts of aphid phenology to target specific control strategies at different times during the growing season. There are several control options, although only some are available to UK growers at present. These include insecticides (pirimicarb, imidacloprid), lettuce cultivars resistant to *P. bursarius* or *N. ribisnigri* and treatment of the seed compost with the entomopathogenic fungus, *Metarhizium anisopliae*, to control *P. bursarius*. In 1996, a series of field experiments were done to target different combinations of control measures during three periods when the risks of aphid infestation were different. The results are summarised in this paper.

Key words: Lettuce, *Nasonvia ribisnigri, Myzus persicae, Macrosiphum euphorbiae, Pemphigus bursarius*

Introduction

In the UK, the foliage of outdoor lettuce crops is infested by three species of aphid (*Nasonovia ribisnigri, Myzus persicae, Macrosiphum euphorbiae*) whilst the roots are infested by the lettuce root aphid (*Pemphigus bursarius*). Previous work at HRI Wellesbourne and in other parts of Europe has indicated that these four aphid species are the major pests of lettuce grown outdoors (Reinink & Dieleman, 1993). *Pemphigus bursarius* and *N. ribisnigri* are specific to lettuce in summer whilst *M. persicae* and *M. euphorbiae* are highly polyphagous and feed on a wide range of plant species (Tatchell *et al.*, 1983). Both *P. bursarius* and *N. ribisnigri* have holocyclic life cycles, overwintering as eggs on their primary host plants which are species of poplar and currant, respectively. In contrast, *M. persicae* and *M. euphorbiae* are largely anholocyclic in the UK and overwinter as adults and nymphs on a range of secondary hosts. Lettuce crops planted sequentially from spring to autumn are exposed to varying risks of colonisation, due to differences in the life cycles of the various aphid species. As a result, there are opportunities to optimise aphid control by targeting specific control strategies at different times during the growing season. The overall aim of this four-year project was to develop an integrated strategy for the control of aphids on outdoor lettuce, targeted at key stages in the aphid life cycles (Ellis *et al.*, 1996).

Although the general pattern of aphid infestation is broadly similar from year-to-year, the precise timing of colonisation by each species varies, depending mainly on weather conditions. One of the main objectives of the project was to use weather data, particularly temperature, to forecast the timing of infestation by each aphid species so that appropriate control measures could be targeted as accurately as possible. Over the last three years, information on the phenology of each aphid species has been collected at several sites. This information is being used to develop and refine temperature-based forecasts of aphid phenology.

The phenological data have shown several periods during the growing season when the risk of infestation by foliage- or root-feeding aphids is different. In 1996, a series of field experiments were done to target appropriate control measures during three periods with differing risks of aphid infestation. These experiments were done at HRI Wellesbourne, HRI Kirton and in Lancashire. There are a number of possible control options, although only some are available to UK growers at present, including insecticides, lettuce cultivars resistant to *P. bursarius* or *N. ribisnigri* and the entomopathogenic fungus, *Metarhizium anisopliae* which causes mortality in *P. bursarius* (Chandler, 1997). These options were used in combination and compared with the control achieved by routine application of insecticides.

Materials and methods

Monitoring aphid populations

Aphid populations were monitored during 1994-1996 by trapping alate aphids and by monitoring aphid numbers on untreated plants. The two methods were expected to provide complementary data.

Alate aphids were captured in water traps, constructed of yellow plastic washing-up bowls, painted black on the outside and fitted with vertical baffles made from yellow Correx^{R}. Two traps/site were placed on the perimeter of lettuce crops at HRI Wellesbourne, HRI Kirton, and in commercial crops in Kent and Lancashire.

Plots of lettuce (cv. Saladin) were planted and grown as a commercial crop at HRI Wellesbourne, HRI Kirton and Burscough, Lancashire, but were insecticide-free. In general, five crops were planted sequentially, so that for much of the time from April to October, two crops were available for sampling. Individual plots were sampled for eight to nine weeks and twenty plants were sampled destructively from each plot once a week. Plants were returned to the laboratory and all aphids were removed carefully and stored in alcohol for later identification. *Pemphigus bursarius* infestations on the roots of the 20 lettuce plants were scored using a logarithmic scale (Wright and Wheatley, 1953).

Different control strategies

In 1996, three experiments were done at HRI Wellesbourne, HRI Kirton and on a commercial farm in Lancashire to assess the effectiveness of different control strategies targeted at different times in the life cycles of the four aphid pest species. The treatments are listed in Table 1. Each plot consisted of two beds of lettuce, each bed containing 4 rows, 22 plants long. A fallow area, the width of a lettuce bed, was left between plots.

Experiment 1

This was planted in late June at HRI Wellesbourne and in Lancashire and was timed to coincide with the peak of *P. bursarius* migration from poplar trees to lettuce. It also coincided with a period of intense foliage aphid immigration and infestation. A number of different control strategies were assessed on two lettuce cultivars, one resistant (cv Robinson) and one susceptible (cv Saladin) to *P. bursarius*. The lettuce were exposed to different insecticide treatments (imidacloprid seed treatment, triazamate sprays, pirimicarb sprays).

The entomopathogenic fungus, *M. anisopliae* was used for the control of *P. bursarius* in one treatment.

The 'routine' plots of cv Saladin (Table 1) received two sprays of pirimicarb each week, whereas in the 'managed' treatment, the foliage of 12 plants/treatment was examined *in situ* twice a week and, if any aphids were found, these plots were sprayed with triazamate. The plots

Table 1. Summary of treatments used in the integrated pest management experiments.

Expt	Cultivar	Seed treatment	Compost treatment	Insecticide
1	Saladin			None
	Saladin			Pirimicarb (routine)
	Robinson			Triazamate (managed)
	Robinson	Imidacloprid		Triazamate (managed)
	Saladin	Imidacloprid	*Metarhizium anisopliae*	Triazamate (managed)
2	Saladin			None
	Saladin			Pirimicarb (routine)
	Saladin			Triazamate (managed)
3	Saladin			None
	Saladin			Pirimicarb (routine)
	T 139			Triazamate (managed)
	Saladin	Imidacloprid		Triazamate (managed)

Key:

Cultivars

Saladin	Susceptible to all aphid species
Robinson	Resistant to *P. bursarius*
T139	Resistant to *N. ribisnigri*

Treatments

Pirimicarb	Routine sprays applied twice weekly (250g/ha in 500l water)
Triazamate	Sprayed if aphids present on any plants of a 12-plant sample (0.4l/ha + 0.5l Swirl adjuvant in 500l water). Crop inspected twice weekly.
Imidacloprid	Seed treatment (180g a.i./100,000 seeds)
Metarhizium anisopliae	Fungus treatment in seed compost for *P. bursarius* control

were irrigated as required.

When the crop was mature, forty plants/plot were sampled to assess yield and quality. In addition, 20 of these plants were broken apart to determine whether aphids were present. The aphids were scored using a logarithmic scoring system (Wright & Wheatley, 1953). Samples of aphids were taken from the heads from each plot and preserved in alcohol for later identification. The root balls from the same 20 plants in each plot were lifted and scored for *P. bursarius* infestation, using the logarithmic scoring system.

Experiment 2

The second experiment was timed to coincide with the period following *P. bursarius* migration and before the late summer/autumn increase in aphids on lettuce foliage. It was planted in mid-late July at HRI Wellesbourne and at HRI Kirton. Aphid numbers were generally low during this period, following the mid-season decline. The lettuce cultivar Saladin was used throughout this experiment. Sampling and harvest assessments were as for Experiment 1.

Experiment 3

The third experiment was timed to coincide with the increase in aphid numbers on lettuce in late summer/autumn and was planted in mid-August at HRI Wellesbourne, HRI Kirton and in Lancashire. A lettuce line bred for its resistance to *N. ribisnigri* (T 139) was included and compared with the susceptible cv Saladin. Sampling and harvest assessments were as for Experiment 1.

Results

Monitoring aphid populations

a. Foliage aphids

Catches in water traps indicated that the numbers of *M. persicae* remained high for several weeks during mid-summer, but that the timing of peak abundance varied both between sites and between years (Figure 1). Flights of *M. persicae* were particularly late in 1996. Again, depending on the year, the largest numbers of apterous *M. persicae* occurred on plants in the insecticide-free monitoring plots from late June to August. Aphid numbers then declined rapidly, usually between late July to early-September, before increasing again, though not in all years, in September/October.

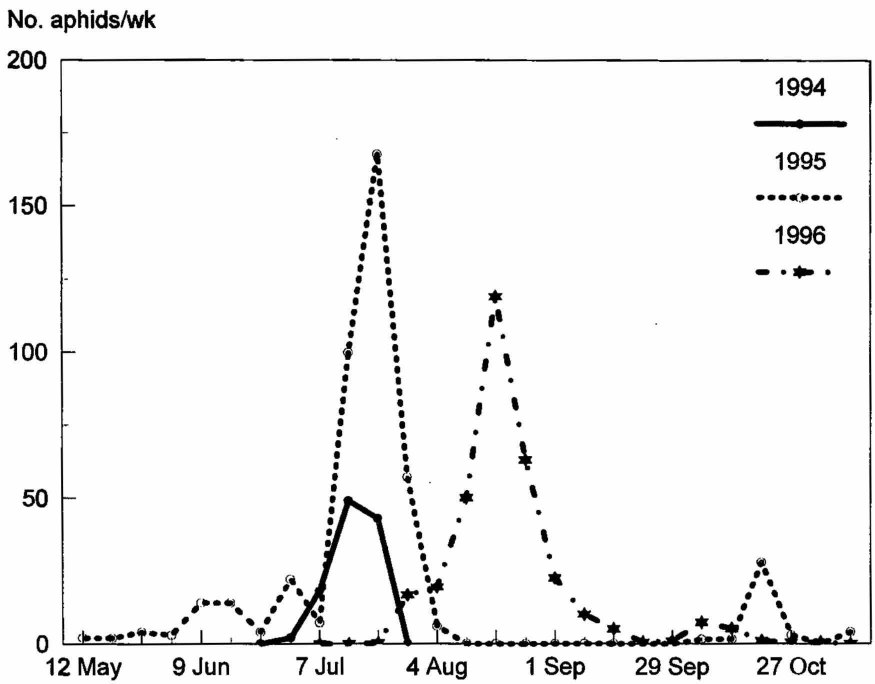

Figure 1. The numbers of alate *Myzus persicae* captured in two water traps placed close to lettuce crops at HRI Kirton in 1994-96.

Alate *M. euphorbiae* were caught in water traps between late June and late August, depending on the year (Figure 2). The first apterae were found on lettuce plants between early May and mid June and the highest numbers were present during mid-June to mid-August. The rapid mid-summer decline in the numbers of *M. euphorbiae* occurred between mid-July and mid-September. In some years, the numbers of apterae on lettuce increased again during September /early October. As with *M. persicae*, the precise timing of immigration and infestation varied from site-to-site and from year-to-year.

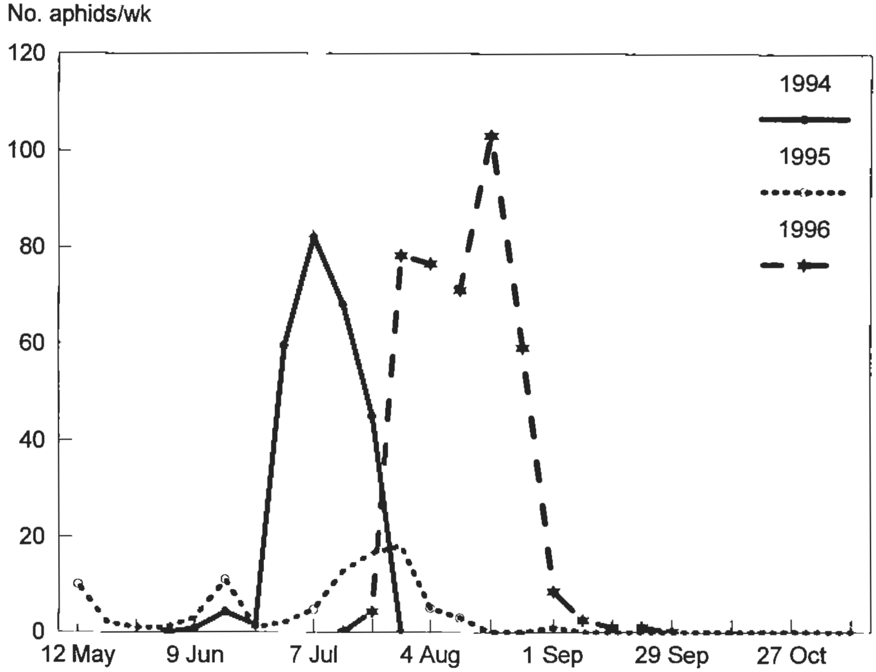

Figure 2. The numbers of alate *Macrosiphum euphorbiae* captured in two water traps placed close to lettuce crops at HRI Kirton in 1994-96.

Few alate *N. ribisnigri* were caught in the water traps. However, larger numbers of both alate and apterous *N. ribisnigri* were found on lettuce plants in the sequentially-planted monitoring plots (Figure 3). Once again there were two periods when *N. ribisnigri* was abundant. In some cases the second peak was the larger. The first apterous *N. ribisnigri* were found on the sequentially-planted plots between early June and mid-July, with the largest numbers occurring during July and early August, depending on site and year. Numbers then declined during mid-July to early September before increasing again during September and October.

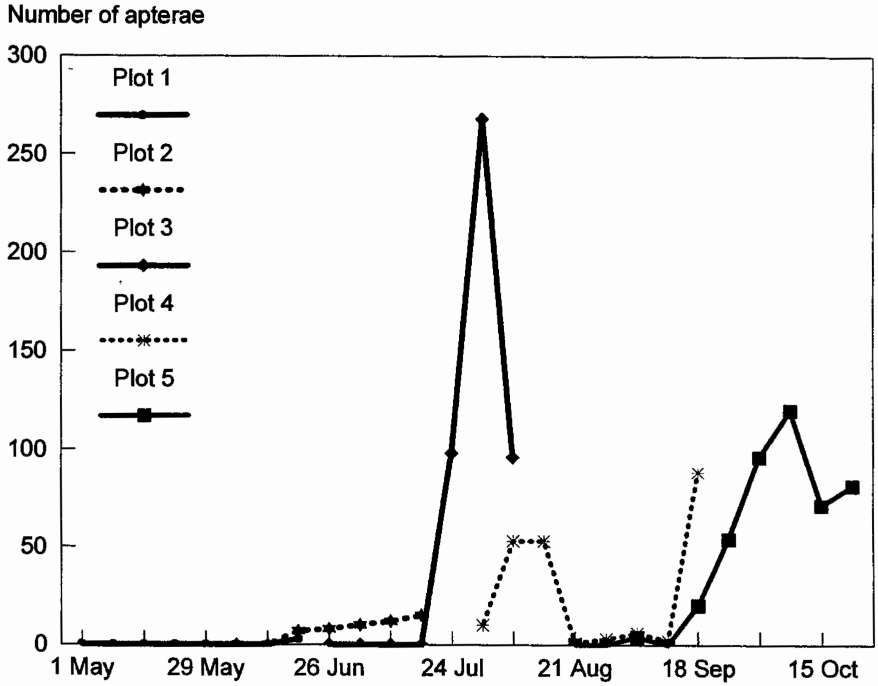

Figure 3. The numbers of *Nasonovia ribisnigri* apterae found on samples of 20 plants taken from sequentially-planted plots of lettuce grown in Lancashire in 1996. The plots were insecticide-free.

Figure 4 shows the percentage of plants whose foliage was infested with aphids in the five sequentially-planted monitoring plots at HRI Wellesbourne. A similar pattern was apparent each year, at each monitoring site, although the precise timings of periods of high and low infestation varied between sites and years. In general, the mid-summer peak in aphid numbers was the result of infestation by all three species, whilst the second peak in early autumn was due predominantly to *N. ribisnigri*.

b. Root aphid

Alate Pemphigus *bursarius* migrated from poplar to lettuce crops during June and July (Figure 5). The earliest date that aphids were first found in water traps was 16 June 1994, in Kent. The latest date was 25 July 1996 at HRI Kirton. The earliest date on which the infestation of plants was detected was 23 June 1995 at HRI Wellesbourne and the latest date was 31 July 1996 in Lancashire.

A preliminary day-degree forecast developed in 1994 (Collier *et al.*, 1995) used a base temperature of 6°C and was based on monitoring data collected during 1987-93. These data were used to produce a new day-degree forecast using a base temperature of 4.4°C (Dunn, 1959). Using this forecast, the start of the aphid migration was predicted to occur after 672 D° from 1

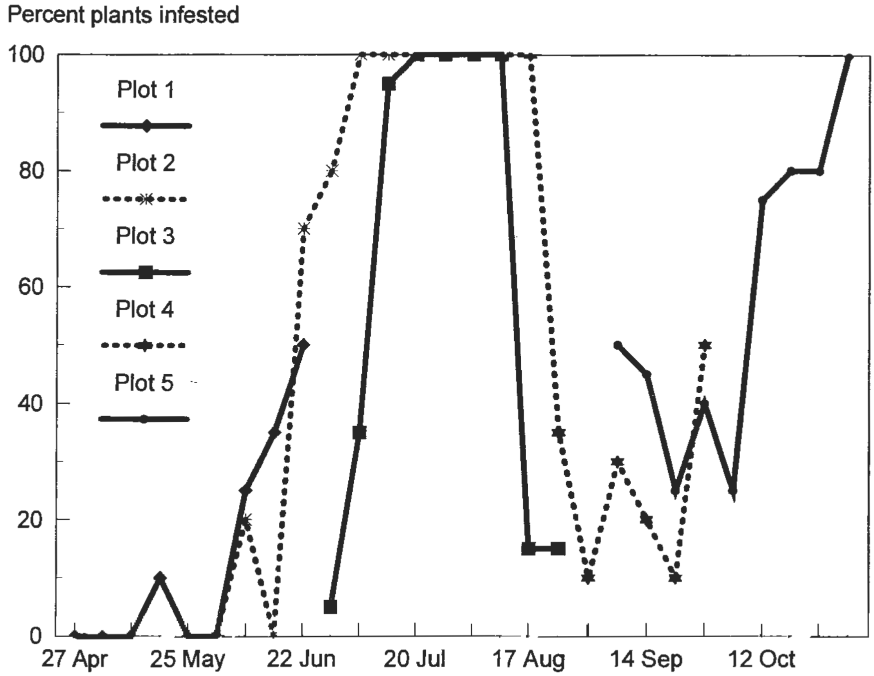

Figure 4. The percentage of plants infested with foliar aphids in plots of lettuce planted sequentially at HRI Wellesbourne in 1996. The plots were insecticide-free.

February. Monitoring data collected during 1994-1996 were compared with this forecast, which was shown to give adequate early warning of the start of aphid migration.

In 1996, the late summer migration of alate *P. bursarius* back to their overwintering sites on poplar trees was detected in water trap catches at several sites in late September/early October.

Different control strategies

In the first experiment, the infestation of *P. bursarius* was extremely small at HRI Wellesbourne, which contrasted with a large infestation of this pest in the crop in Lancashire. At both sites, cv Saladin was infested by *P. bursarius* whilst cv Robinson was completely resistant.

Routine treatment with pirimicarb had no significant effect on infestation by *P. bursarius* at either site, but the combination of imidacloprid, triazamate and *Metarhizium* fungus controlled *P. bursarius* on cv Saladin at both sites.

Aphid infestations of the foliage were small at HRI Wellesbourne but large in Lancashire. Pirimicarb sprays failed to control aphids on the lettuce foliage at both sites. While applications of triazamate reduced aphid numbers on lettuce foliage at the Lancashire site, no benefits from triazamate were observed at HRI Wellesbourne, probably because aphid numbers were so low.

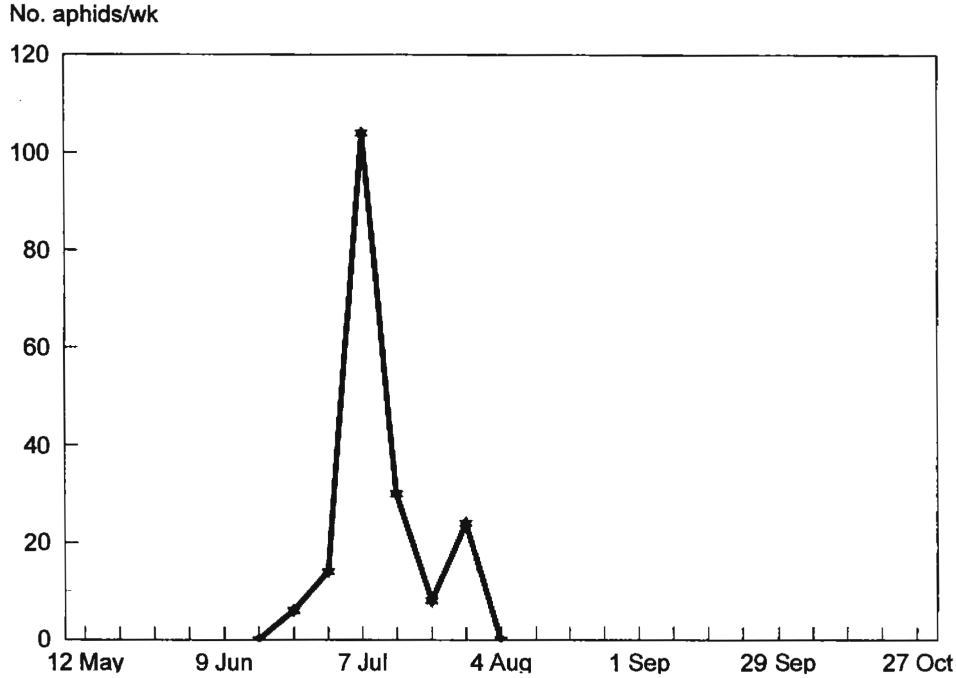

Figure 5. The numbers of alate *Pemphigus bursarius* captured in two water traps at HRI Wellesbourne in 1994.

In the second experiment, *P. bursarius* infestation was very small at HRI Wellesbourne (less than 1% of plants) but a large infestation (up to 60% of plants infested) occurred at HRI Kirton. The infestation of *P. bursarius* was reduced significantly on cv Saladin at HRI Kirton by repeated applications of pirimicarb and almost completely eliminated by applications of triazamate. At HRI Wellesbourne, chemical treatments had no effect on the very small numbers of aphids on lettuce foliage, whilst at HRI Kirton, the numbers were reduced by triazamate sprays compared with the untreated plots and with the plots sprayed routinely with pirimicarb.

In the final experiment, which was done at three sites, infestations of lettuce foliage were very low at HRI Wellesbourne and HRI Kirton. In Lancashire, there was a more severe infestation of aphids, particularly *N. ribisnigri*, and 90% of untreated cv Saladin were infested. *Pemphigus bursarius* was recorded at HRI Kirton and in Lancashire, but infestations were small. No *P. bursarius* were detected in this experiment at HRI Wellesbourne. The advanced breeding line T139 was resistant to *N. ribisnigri* but supported populations of *M. euphorbiae* and *M. persicae*. The combination of the resistant cultivar and triazamate sprays reduced the numbers of aphids on lettuce foliage and, on cv Saladin, the combination of an imidacloprid seed treatment and triazamate sprays was also effective. Routine sprays of pirimicarb were less effective.

In all experiments, the major pest on lettuce foliage was *N. ribisnigri*, particularly in September and October, at the end of the growing season. At HRI Wellesbourne and HRI Kirton, regular crop monitoring did not reduce greatly the numbers of triazamate sprays applied compared with the routine programme of twice weekly pirimicarb sprays. Similarly, imidacloprid seed treatment did not reduce the numbers of triazamate sprays applied subsequently. However, in Experiment 3 in Lancashire, an average of only 4 sprays of triazamate was applied to the managed plots compared with 14 routine sprays of pirimicarb.

Discussion

The data collected from the water traps and the sequentially-planted plots of lettuce confirmed that there are a number of discrete periods during which the relative abundance of the four pest aphid species of lettuce is different. It is equally clear that the timing of these periods differs between sites and years. For example, the mid-summer period of high aphid colonisation by *M. persicae* and *M. euphorbiae* occurred several weeks later in 1996 than in either of the two previous years (Figures 1 & 2).

One the objectives of the project was to use weather data to forecast the timing of infestation by each species so that appropriate control measures could be targeted as accurately as possible. *Pemphigus bursarius* has a holocyclic life-cycle in the UK, overwintering as diapausing eggs on poplar and it appears that a simple day-degree forecast, using a base temperature of 4.4°C (Dunn, 1959), will provide adequate early warning of the start of the aphid migration from poplar to lettuce. It is likely that the phenology of *N. ribisnigri,* which also has a holocyclic life-cycle and overwinters on species of currant, may be predictable also using a simple day-degree forecast. However, at present no data have been published to suggest a suitable base temperature.

In contrast, both *M. persicae* and *M. euphorbiae* are highly polyphagous species with mainly anholocyclic life-cycles in the UK and they overwinter as adults and nymphs on a range of hosts. Using data collected from suction traps run by the Rothamsted Insect Survey, Harrington *et al.* (1990) have identified a strong negative correlation between winter temperature (January-February) and the first date on which *M. persicae* or *M. euphorbiae* are found each year in suction trap samples. This type of relationship may provide a more reliable forecast of the first appearance of these two species in lettuce crops than a forecast based on the accumulation of day-degrees in the spring.

This study provides further evidence to support the existence of a mid-season decline in the abundance of aphids on lettuce, often termed the aphid 'crash'.
The reasons for this crash are unclear but might include the effects of natural enemies, entomopathogenic fungi, host plant quality, environmental conditions (such as high temperatures), and intrinsic factors of aphid biology (Nunnenmacher, 1996). It was not possible to identify individual causal factors from the present study.

Although once considered an infrequent pest in the UK, *P. bursarius* is now believed to be a constant threat to lettuce crops established during the late spring and summer. Ellis (1991) suggested that a number of factors, including warm, dry summers, mild winters, the intensification of lettuce production and the use of some cultivars of iceberg lettuce, which appear to be highly susceptible, may have contributed to this change. In addition, the number of insecticide options available has been reduced. As a result, in recent years *P. bursarius* has become a much greater problem for lettuce growers in the UK. Of the control options evaluated in Experiments 1-3, several show considerable scope for *P. bursarius* control, including the incorporation of *M. anisopliae* into the seed compost (Chandler, 1997) and the use of resistant cultivars such as cv Robinson. Of the insecticides, imidacloprid is effective, at least against low infestations of *P. bursarius* (Parker & Blood Smyth, 1996) and foliar sprays of triazamate were shown to be effective in the experiments described here. At present, triazamate is not approved for use on lettuce in the UK.

The advanced breeding line T139 was resistant to *N. ribisnigri* but supported populations of *M. euphorbiae* and *M. persicae*. This pattern of infestation was as expected because this lettuce was bred for its resistance to *N. ribisnigri* alone. Of the insecticides applied against aphids on foliage, either triazamate sprays alone, or triazamate sprays in combination with imidacloprid seed treatment, were the most effective treatments and provided good control.

The insecticide spray treatments were either applied routinely (pirimicarb), or in response to aphid presence following inspection of the crop (triazamate). In most cases, regular inspection of the plots to determine the presence of aphids on lettuce foliage did not reduce greatly the numbers of triazamate sprays applied, when compared with the routine programme of twice-weekly pirimicarb sprays. Similarly, using an imidacloprid seed treatment did not reduce the numbers of triazamate sprays that had to be applied subsequently. This was an unexpected result, as triazamate appears to be a very effective aphicide (Parker & Blood Smyth, 1997; Sweeden & McLeod, 1997) with relatively long persistence (R. Collier, unpublished data). One possible reason for the perceived over-application of triazamate is that the method used to determine whether further insecticide treatments should be applied was inappropriate. For example, imidacloprid does not have as pronounced an effect on the numbers of alate aphids found on treated crops as it does on colonisation by apterous aphids (Dewar & Read, 1990). It may be that the application of foliar sprays, particularly on imidacloprid-treated crops, should be based on the presence of apterae rather than alate aphids. This may well maintain levels of control but reduce significantly the numbers of sprays applied.

Résumé

Stratégies pour la lutte contre les pucerons de la laitue.

En Angleterre, le feuillage extérieur des cultures de laitues de plein champ est infesté par trois espèces de pucerons (*Nasonovia ribisnigri, Myzus persicae, Macrosiphum euphorbiae*) tandis que les racines sont infestées par le puceron des racines (*Pemphigus bursarius*). Cet article décrit la phénologie de chaque espèce de puceron, en utilisant les données de surveillance collectées sur plusieurs sites pendant trois ans. Cette information est utilisée pour développer et affiner la prévision de la phénologie des pucerons en relation avec la température. Les données phénologiques ont montré plusieurs périodes durant la saison de production ou le risque d'infestation du feuillage et d'attaque des racines change. Ainsi, il est opportun d'utiliser la prévision de la phénologie des pucerons dans une stratégie de lutte ciblée spécifique aux différentes périodes de la saison de production. Plusieurs options de lutte existent, bien que seules quelques unes soient utilisables pour les producteurs anglais actuellement. Cela inclut des insecticides (pirimicarb, imidacloprid, triazamate), des variétés résistantes à *P. bursarius* ou à *N. ribisnigris* et le traitement du lit de semence avec des champignons entomopathogènes, *Metarhizium anisopliae* pour lutter contre *P. bursarius*. En 1996, une série de parcelles expérimentales ont été mises en place pour cibler différentes combinaisons de mesures de lutte durant trois périodes dont le risque d'infestation par les pucerons était différent. Les résultats sont résumés dans l'article.

Acknowledgements

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Consideration of "Integrated Production" guidelines for vegetable crops

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Key words: Integrated pest management, integrated production, guidelines

Introduction

During the last 10 years, there has been a remarkable shift away from systems of Integrated Pest Management (IPM) to ones based on Integrated Production (IP). Growers and Supermarket chains have started to produce and market IP-products in many localities. In general, such products are labelled in a specific way so that they can be marketed as produce from environmentally friendly systems. The two commodities of most current interest are fruits and vegetables, as both are "high value crops" and as a consequence are subject usually to a high number of pesticide treatments. While the IOBC/WPRS has led the initiatives to produce guidelines from IP in fruit crops, the Working Group on Field Vegetables has up to now been reluctant to produce such guidelines. With the hardening attitude of society in general, the IOBC/WPRS is, according to its own remit urged to reconsider this.

The purpose of IP

Dr Hans Steiner from Germany suggested changing from IPM to IP system in several oral presentations he made during the late 1960s. He was convinced that IP was the next step of development to ensure that IPM did not become restricted solely to supervised control (improved usage of pesticide through pest monitoring). The reason for the current interest, however, appears to be based mainly on the growing concern about pesticide residues in food and drinking water, the adverse effects of pesticide on the environment (biodiversity etc) and problems within the EU of local overproduction of food. Following the recent development of interest, IP may now be described as:

1) a concept for an ecologically-favourable and economically-improved system of crop production.

2) a production system which can meet the various Government (and EU) restrictions as well as criteria for special labelling (high quality) of the produce which can then demand higher prices.

The first point has clear links to the historical background for IPM in the 1950s and 1960s, which was concerned with the uneconomical use of insecticides, the threat to beneficial invertebrates in particular, and to the environment in general. In contrast to this, the second, and newer, point represents the struggle of modern, industrialised farmers to turn the problem of legally-imposed reductions in inputs, such as fertilisers and pesticides, into a system that has economic benefits. In this struggle, special labelling is of considerable benefit to the producers. However, such labelling has little meaning if the promises made on the labels are not only defined clearly but also subjected to some kind of control. This is the area in which IP-guidelines have become relevant and in which the IOBC/WPRS has played an instrumental role through its Guidelines Commission and their general publication in 1993 (El Titi *et al.*, 1993).

The general IP-guidelines related to vegetable production

According to the general IP-guidelines (El Titi *et al.*, 1993) field vegetables should be regarded as an annual crop where *the entire farm is the unit of IP, crop rotation is mandatory, involving a minimum of four crops, and IPM is the strategy used as the basis for crop protection.*

The above demands have considerable impact on a great number of vegetable growers in Western Europe, where highly specialised small units, which can hardly be called "farms", are fairly common. On such units, often only one or two kinds of field vegetables are produced in highly intensified systems. Crop rotation is generally absent, or almost so, and problems with pests and diseases are overcome by the routine application of chemical treatments. Besides the lack of crop rotation, possible benefits from crop rotation on a major pest, the cabbage root fly, are reduced considerably in many areas because the growing of oilseed rape is widespread. With such obstacles to the IP-guidelines, the introduction of IP for of field vegetable crops will not be easy. In addition, one may ask whether there will be major problem areas if the Working Group on Field Vegetables is to produce a set of guidelines. Such guidelines will be along the lines of the Technical IOBC Guidelines III, which are the *IOBC Guidelines that define the minimum requirements for specific crops or farm sectors.*

Specific IP-guidelines for field vegetable crops

For field vegetable crops, the immediate overwhelming problem in the number of crops involved. For example, there are about ten different types of *Brassica* crop and some crops are so small in terms of area and number of growers that very little has been done about their pest and disease problems.

Possibly the most crucial question is how to give advice concerning diagnostic methods, particularly on aspects such as control thresholds. The general principles on thresholds are spelled out under the strict IOBC Guideline rules (risk assessment, p. 37, El Titi *et al.*, 1993) as follows: *robust but scientifically sound threshold values are essential components for decision making.*

Despite the many years of work claimed to be directed towards IPM, few thresholds are available. In the case of Brassica crops, it has been possible to develop a reasonable and robust binomial counting system for all caterpillars (Theunissen & den Ouden, 1985).

However, the worst pest, the cabbage root fly (*Delia radicum*) still remains a problem with respect to control thresholds. The carrot fly (*psila rosae*) is another major pest, which has been studied in great detail. The results are reasonably good considering the starting point (Esbjerg *et al.*, 1988) but it is still difficult to reach the desired level of precision and be certain that the risk of making a wrong decision is low.

Among the few examples of pests being managed according to a whole series of threshold values, under different trap catch levels, different crops and different weather conditions, is that for forecasting attacks by the common cutworm (*Agrotis segetum*) in

Denmark and Southern Sweden (Esbjerg, 1988, Esbjerg *et al*, 1996). This example demonstrates the profitability of such an approach (Esbjerg, 1987) even when dealing with a sporadic pest.

However, this example of work over more than ten years shows also how demanding it is to collect sufficient field data to cover, by means of trial and error, the gap from trap catch to later damage which can never be covered fully by experimentation.

Further attempts towards IP-guidelines for field vegetables?

With the problems described already it may appear to be near to impossible to work out IP-guidelines for field vegetable crops. However, the interests shown in this subject by grower associations and supermarket chains show that it is necessary to some degree. The question to be resolved is whether IOBC/WPRS has something particular to offer and how to avoid becoming involved too much in trade policy rather than in scientific matters.

Initially it would seem important that the Working Group on Field Vegetable Crops tries to concentrate its efforts on a few crops, on which Group members already have considerable expertise, to avoid overburdening its members. In this respect the relevant crops to select might be Brassica, carrot and perhaps leek/onion crops.

With regards to the dilemma between "science" and "policy matters" some principles may be suggested. First it may be a good idea to try working out ideal ways of handling IP based solely on scientific experience, without caring unduly about systems like monocropping of vegetables on small areas, or localised problems on special areas. (According to good IP-principles, the total crop should not be produced in an area where certain problems are bound to occur). Guidelines produced in such a manner may assist local organisations who want to develop their own specific guidelines based on the overall IOBC/WPRS principles, Such an approach may also be attractive to national authorities and in the optimum situation to the EU. Last, but not least, the important positive effects of adopting such principles may be:

1) to avoid creating politically-oriented conflicts which could destroy the current open and productive climate of the Field Vegetable Working Group.

2) to avoid producing IP-guidelines, which because of being made acceptable to many different producer and marketing-organisations, will be so diluted that IP has no true meaning and will obtain little confidence from the consumer.

Both points may be regarded as extremely important to the IOBC/WPRS in general.

Résumé

Considération sur les recommandations de la « Production Intégrée » en cultures légumières

Durant les 10 dernières années, des changements remarquables ont été fait sur les systèmes de culture depuis la protection intégrée des ravageurs (IPM) jusqu'à ceux basés sur la Production Intégrée (IP). Les cultivateurs et les chaînes de supermarché ont commencé à produire et à vendre des produits IP dans plusieurs localités. En général, de tels produits sont labellisés d'une manière spécifique de telle manière qu'ils puissent être commercialisés comme étant produits dans des systèmes environnementaux favorables. Les deux denrées d'intérêt les plus courants sont les fruits et les légumes, à la fois parce que ce sont des cultures de « forte valeur » et parce qu'elles font l'objet habituellement de nombreux traitements insecticides. Tandis que l'IOBC/WPRS a pris des initiatives pour rédiger des recommandations pour la Production Intégré en cultures fruitières, le groupe de

travail sur les cultures légumières s'est, jusqu'à présent, peu engager pour rédiger les recommandations qui le concernent. Au regard de la demande pressante de la société en général, l'IOBC/WPRS encourage vivement le groupe à reconsidérer sa position.

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Managing pest Lepidoptera on processing vegetable crops in the Midwestern United States

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Abstract: Vegetable insect pest management requires an awareness of the interaction of plant phenology, insect behaviour on the crop, and insect populations. The large landmass of the midwest United States allows seasonal predictions to be made as a result of the stable weather patterns and the predictable air mass movement. There is a 4 day biological difference for every 1° latitude, 5 ° longitude, and 400 ft. in elevation moving north, east and up in the spring and the converse in the fall. In the Midwest, the planting period for sweet corn and green beans is April to August with subsequent harvest from June to October. The few thousand hectares of processing vegetables are surrounded by millions of hectares of field corn and soybeans. Insects must disperse from these field crops to the vegetable fields. It is the monitoring of the pest level and dispersal pattern that make our system unique. Commercial evaluations and small plot trials have determined the control characteristics of current insecticides applied during the entire season at several locations. The information is used to vary rate and interval of applications and determine the treatment period. Doubling the insecticide rate will only increase control from residual materials by 3-5% while doubling the interval will result in the loss of control by 10-30%. Treatments closer than 20 days before harvest do not improve control in commercial fields. These factors provide a narrow treatment window. Knowing the pest, the crop, and the control tools have allowed us to reduce significantly the treatment costs required to produce uncontaminated, high-yielding vegetable crops.

Key words: Pest profiles, *Ostrinia nubilatis*, *Helicoverpa zea*, "windows of vulnerability"

Introduction

The large level land mass of the Midwestern United States allows seasonal weather predictions to be based on stable weather patterns and predictable air mass movement. A model indicates that there is a 4 day difference in the phenology of pest activity for every 1° latitude, 5° longitude, and 122 m in evaluation as one moves north and east across the cropping area. Such increases proceed upwards in the spring and downwards in the fall. This phenomenon allows for early- and late-season production south of our Wisconsin and Illinois processing facilities. Southern production areas can be utilized to obtain earlier season vegetables, which allows us to start the processing earlier and so obtain more out-put from our processing plants. Early plantings in this area will avoid major insect problems by harvesting the crop prior to second generation flights of the main lepidopteran pests. The systematic planting from south to north requires planting to be coordinated in several different climates. Models for forecasting planting and harvesting times have been developed to insure the uniform flow of vegetables to the processing plants. Pest management programs are also adjusted to suit specific crop production areas.

The occurrence and severity in the pest insect populations is affected by the growth stage of the vegetable crop at the time of infestation. Vegetable pests are not present at the time of planting and hence must migrate into the fields. This paper reviews pest and crop interactions, pest monitoring systems, and our research protocols. The level of control required is adjusted to the ability of each processing plant to remove various types of contamination. The information is assembled to develop a pest management program that is tailored to this multi-state production system.

Vegetable insect management requires knowledge of the behaviour of the insects on the crop, the type of damage the insects inflict, the insect population thresholds, and the characteristics of the required insecticides. Damage or loss to pest insects has been defined in terms of quantitative yield loss, the cost of removing the larval contamination, and/or the cost of not removing the larval contamination. Such information is obtained from samples taken to determine the number, size and species of pest insect per unit of product (threshold) at harvest.

The interaction between the crop and the activity of the pest insect defines a "window of vulnerability" that is used to focus our pest management programs. Information on production practices, the behavior and dispersal patterns of key pests, in conjunction with plant maturity are used as the benchmarks to define the "treatment window" within the "window of vulnerability". The treatment window is the period insecticide control may be required, depending upon the information collected concerning the pest insect populations.

Pest Profiles As They Relate To Insect Management

European corn borer (Ostrinia nubilatis)

Larvae of the European corn borer will damage sweet corn from when they are about 15 cm tall to harvest, which depending on variety and planting date generally covers a period of from 75-100 days. The larvae damage the leaves, stalk, tassel shank and ear. In green beans, European corn borer larvae can feed on plants from the third true leaf stage until harvest, a period of 50 to 70 days. Control is simplified by the availability of consistent, reliable adult monitoring tools, which include black light traps and sampling moths from "action-sites" (mating and feeding areas). These tools are used to estimate adult dispersal. The insects caught are examined to determine the reproductive status of the female moths. The percentage of newly-mated females indicates whether or not dispersal has not peaked and whether, or not, re-infestation is likely to occur. European corn borers overwinter as larvae and then pupate in early spring.

Moths of the first generation emerge after approximately 375 HU50, (Figure 1) and of the second generation after 1575 HU50 (Figure 2). Daily heat units are accumulated from April 1, the average temperature above 50 F° representing the daily heat unit. The moths congregate in grassy sites to mate and drink free water. Their potential for egg-laying can be determined by sampling moths at such sites (Figure 3). Black light traps are used to collect moths as they disperse to and from these grassy action sites. European corn borer larvae increase in length by approximately 1 mm/day (Table 1).

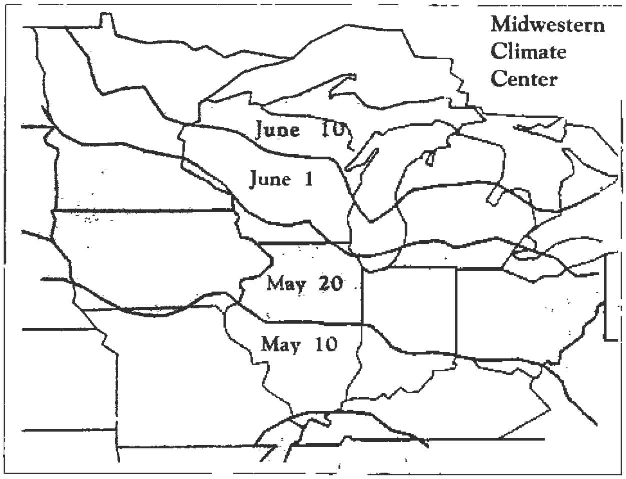

Figure 1. Projected dates for first generation European corn borer flights based on average degree day accumulation (date when 375 degree days accumulated above a base temperature of 50 °F).

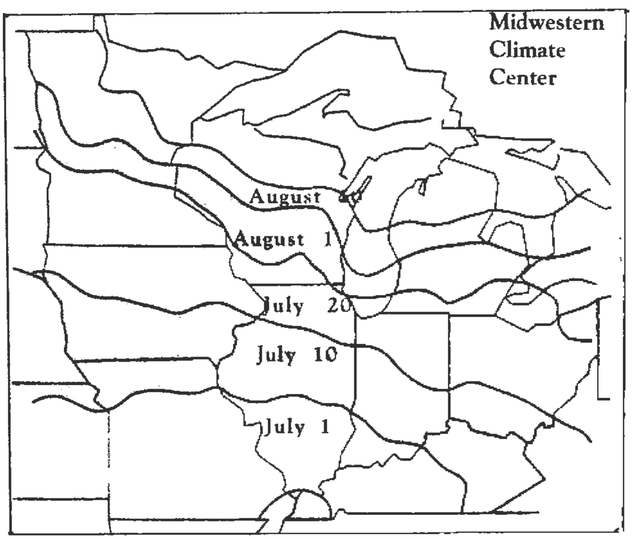

Figure 2. Projected dates for second generation European corn borer flights based on average degree days accumulation (date when 1575 degree days accumulated above a base temperature of 50 °F).

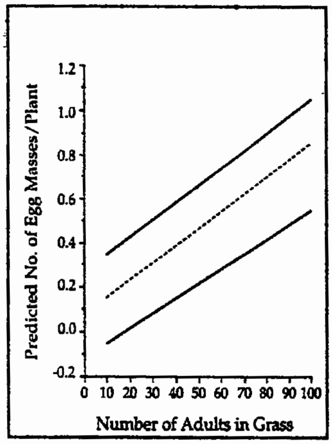

Figure 3. Predicted number of European corn borer egg masses per corn plant, based on number of European corn borer moths per 10 m of dense grass (Showers *et al.*, 1989).

Table 1. European corn borer instar size and stage chart with approximate age for each stage.

Growth Stage	Body Length (mm)	Head Capsule Width (mm)	Days from Hatch at 22° C
Egg Mass	*	*	0
1 Instar	1-2	0.3	1
2 Instar	3-4	0.4	5
3 Instar	5-10	0.7	10
4 Instar	12-16	1.0	15
5 Instar	19-25	1.7	20

A crop development term was needed that reflected a uniform stage of crop development and that related to the pest management program. A "*row tassel*" benchmark term was developed. Row tassel is defined as when you can look down the crop rows and see rows of tassels in the majority of the field, pollen and silk are present. Processing sweet corn will row tassel about 35 to 28 days before harvest. This benchmark can be determined without entering the field and can be predicted several days in advance to allow timely treatment of lepidopteran pest infestations that are already on the plants.

The optimum "*treatment window*" is the period during susceptible larval feeding patterns and control of potential problem larval stages. The first and second instar larvae feed initially on the leaf tissue in the whorl. At the third instar stage, the larvae bore through the leaves and move into the pollen baskets on the tassel. The larvae are well protected during this period. Larvae will leave the tassel whorl and become exposed when the tassel is emerging, just prior to row tassel. Larval will move down the plant into the stalk or small ear. Infestations after row tassel consist of minor leaf feeding then boring into the stalk or ear. Larval damage or contamination is not considered a problem if the infestation occurs within 18 days of harvest. European corn borer larvae need to reach the fifth instar, approximately 25 mm in length, before they are considered a contamination problem. The processing plant equipment will successfully remove the smaller larvae. Processing methods to consistently remove the larger larvae are currently being developed. European corn borer can also reduce crop yield if infestations occur prior to row tassel.

The prediction of larval development, adult dispersal, and feeding pattern helps to define accurately the period when treatment is required. When European corn borers are present, the "*window of vulnerability*" can last from seedling to harvest. The treatment window is pre-row tassel to 18 days before harvest, less than a 2 week period (Figure 4).

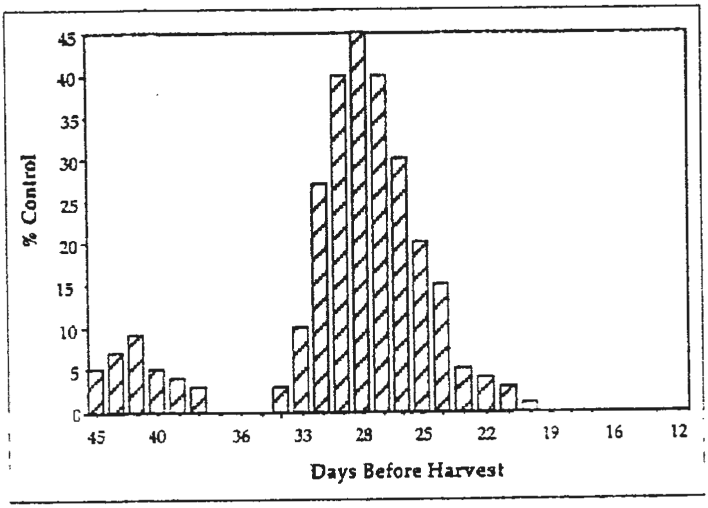

Figure 4. The relative value of insecticide applications from whorl stage to 12 days before harvest when pest insects are present. Row tassel occurs at 28 days before harvest.

Corn earworm (Helicoverpa zea)

Corn earworm do not usually overwinter in the northern part of the midwest states, such as Minnesota, Wisconsin, and Michigan. The first generation of moths is usually small and of limited importance to sweet corn or green beans. Prevailing winds move the moths northward in the summer and southward in the fall. Control problems arise when large air masses (LOWS) move from the Gulf states through the midwest. Corn earworm migrations occur in wind directions of 135 - 225 (SE-SW) at above normal temperatures and dew points when the barometric pressure is low. The female moths lay more eggs during high pressure periods and disperse more during low pressure periods. Weather patterns are monitored to track the potential of the moths both to disperse and to lay.

Corn earworms feed directly on the corn ears, the window of vulnerability being from silking to 18 days before harvest. Eggs are laid directly on the ear in the silk. The small larvae move down the silk and into the protection of the ear. Adult control is critical to population management. Small larvae resulting from infestations closer than 20 days before harvest are removed by processing equipment.

Monitoring Systems

Data collected from networks of black light traps and pheromone traps coordinated by state entomologist to track the moths of both the European corn borer and the corn earworm. In addition to these data, Del Monte has 15 years of pheromone trap data and over 40 years of black light trap data from our midwest production areas. These data can be reviewed to aid in prediction. We can predict problem years from weather observations. Corn earworm flights occur in northern Illinois when at least 100 moths are caught/night for 10 consecutive nights in southern Illinois during first generation flights of moths in May.

Pheromone traps have not been as successful for the European corn borer as for the corn earworm. Evaluation of traps has demonstrated that the wire Hartstack trap used with Hercon® lures has given the most consistent results. Comparison of pheromone traps located in fields of various attraction help us to interpret the trap results. Pheromone traps only collect males. High numbers (100+/night) do not reflect high infestations, as males may simply be aggregating to find low numbers of females. If uniform high number are caught in multiple traps that have varying levels of attractiveness, then major migration has occurred. When trap catches vary, the result reflects a local re-distribution of males seeking females. The trap data only measures dispersal of males and not survival. Fields have to be sampled to verify the data concerning the numbers of moths caught. The black light trap gives a more robust estimate of the population of corn earworms, even though it catches fewer moths/night than the pheromone trap. Corn earworm flights occur after the vast majority of the sweet corn has reached the row tassel stage. Sweet corn requires treatment from the row tassel stage to 18 days before harvest. Captures of European corn borers and corn earworms from 35 years of black light trap data in combination with 15 years of corn earworm pheromone trap data provide a useful tool to predicting the infestation periods, the population levels and the year-to-year population trends. Key dates for first flight of 10+ moths/night, first re-infestation flight (100+ European corn borer/night or 10+ Corn earworm/night in the black light), and average number of nights at these levels, serve as benchmarks to indicate whether the control program needs to be modified. Monitoring moth numbers measures only moth dispersal and not moth survival. Survival is monitored at the processing plant by recording which instar stage of the two moth species is present in the 100-ear sample.

The infield or field edge monitoring of *grassy action sites* is a useful predictor of pest pressure. European corn borer moths seek "dew solutions" which they require for maximum egg production. Dew form first on hairy grasses. The males congregate at these sites to await females. Sampling moths from these sites allows the survival and mating status of the population to be estimated. The decline in numbers of European corn borers at such sites indicates when the population has peaked and when further infestation of treated fields is unlikely.

Field sampling consists of a selection of representative fields at the growth stages vulnerable to infestation. The lepidopteran pest are randomly distributed in the field, but clumped near the ear zone on the plant. Five sets of 10 plants per field are examined to assess egg masses, larval numbers, and crop damage. Egg mass color can be used to determine the day of infestation: light cream, cream, light brown, and blackhead stage for 1,2,3, and 4+ day old eggs masses, respectively. Each larva is identified to species and instar to determine the success of the treatment programs and to correlate to trap and field observations. Infestations cannot be destroyed once the ears become infested. The information from the field samples is used to make adjustments to the current treatment program during the current treatment window. The abundance of small larvae at harvest is an indication of a significant population that may require higher rates, the application of a different insecticide, and/or fewer days between treatments.

Research Protocols and Evaluation Methods

Small plot trials are done at a designated crop stage to test different spray intervals and different treatment rates. Data from the last 20 years has demonstrated that doubling the rate of insecticide applied over same time interval improves residual insecticide control by 3-5%. A change in spray interval at the same rate will reduce control by 15-30%. Any delay in starting the spray program before the pre row-tassel results in a 10% loss in control for each days delay. Moths, larvae and eggs are sampled throughout all trials to evaluate the level of re-infestation. Blacklight trap and pheromone traps are located near to the test sites. Heat unit calculations are made to time the intervals both between the spray treatments and between the last treatment and harvest. At harvest, the damage/ear and the species and size (age) of the larvae present are analyzed. Such data indicate the range of control achieved from each insecticide.

Small plot trials have multiple untreated checks that are used to determine pest levels in the blocks. Depending upon the year, the level of undamaged ears in the untreated check plots will vary from 3% to 60%. In low pressure years, untreated checks in the short interval treatment blocks may have cleaner corn resulting from adult mortality and low levels of re-infestation. In average years, the small plot untreated checks are not affected greatly by adult mortality. The small plot trials are designed to be a worst case scenario for both European corn borers and root earworms. Adult mortality is not evaluated in these trials.

Adult mortality is evaluated in large-scale commercial field trials that are treated with sprays applied from aircraft. In addition, commercial programs are monitored and the levels of control achieved are evaluated at harvest. The fields are evaluated in the same manner on the small plot trials. The entire season's data is recapped as to the treatment program, the pest activity and the control achieved. The recap has clearly demonstrated that treatment closer than 18 dbh at best will improve control by 0% - 3%. The value on a per treatment basis is illustrated in Figure 4. The maximum control can be obtained just prior to row tassel to 18 dbh. The graph defines the "treatment window". The use of field observation of insect behavior, research data, and constant control evaluations was used to outline the pest management program in the form of a table.

The Handy Dandy Sweet Corn Chart (Foster & Flood, 1995) (Table 2, Figure 5) was produced to reflect the control program over the entire season. The treatment window can be placed in each block of planting dates, one through six, and adjusted for the insects present in the crop. The sweet corn crop is in the field for 70 to 100 days depending on variety, location, and planting date. The sweet corn window of vulnerability ranges from 25% to 90% of the season, but the treatment window extends over only 0 - 15% of the season.

Compiling the data in this way has allowed us to determine the value of each treatment to the overall control program. This systematic approach has provided a major advancement for lepidopteran pest management programs in crops of sweetcorn and beans used for processing.

Table 2. How to use the Handy Dandy Sweet Corn Chart.

Planting	Pest	Crop/Pest Stages	Threshold Timing
(1) Early hybrid (2) Late hybrid	1st generation ECB	Although both have been in ground the same length of time (1) is more mature than (2). (1) is at a higher risk than (2). If you are within 14 days of RT, wait until your pre-row tassel spray.	*%Whorl injury* / *Pounce 1.5G® whorl treatment 14 days before RT* / *Pre-row tassel treatment* 0: - / - 10: - / (Look at picnic btle. activity) 20: + or + 50: + and/or + 70: + and + *Note:* Adult mortality is not an issue as adults have laid eggs and died by now.
(1) Early hybrid	2nd generation ECB	(1) corn is within 15 days of harvest. ECB are not an issue.	No treatment required.
(2) (3) Planted first half of May	2nd generation ECB	(2)(3) Corn has row tasseled before start of flight & corn is more than 20 days from harvest. Examine fields for ECB.	Plantings (2) and (3) - If ECB eggs or larvae are detected and adult ECB are in action sites, and corn is more than 18 days before harvest (DBH) for processing corn or more than 10 DBH for fresh market corn - treat (1 application)
(4) Planted second half of May	2nd generation ECB	Corn row tassels after start of flights.	Apply 1st application within 4 days of first ECB flight and if the flight continues, apply a 2nd application in 150 heat units base 50 or about 5 days. Stop treatment 18 DBH for processing sweet corn or 10 DBH for fresh market corn.
(5) Planted first half of June	ECB & CEW	Sweet corn row tassel more than 14 days after the start of ECB flight. ECB infestation already in whorl and adults laying eggs.	Treat 2 days before row tassel as tassel emerges from whorl to expose ECB larval. Protect the silks by silk spray. Do not let the crop go more than a 50% change in percent silking between treatments if CEW are being caught in the trap. Follow with an application in 100 heat unit base 50 (4 days). Stop treatment 18 DBH for processing sweet corn or 10 DBH for fresh market corn.
(6) Planted second half of June	ECB & CEW	Row tassel more than 21 days after start of flight of ECB. Rootworm beetles feeding and adult ECB in field.	Examine whorl (Aug. 5-15) to determine if whorl damage thresholds are met. Refer to planting 1. Do not use a granular because you want to kill adult ECB also. Pick up planting 5 program at pre-row tassel.

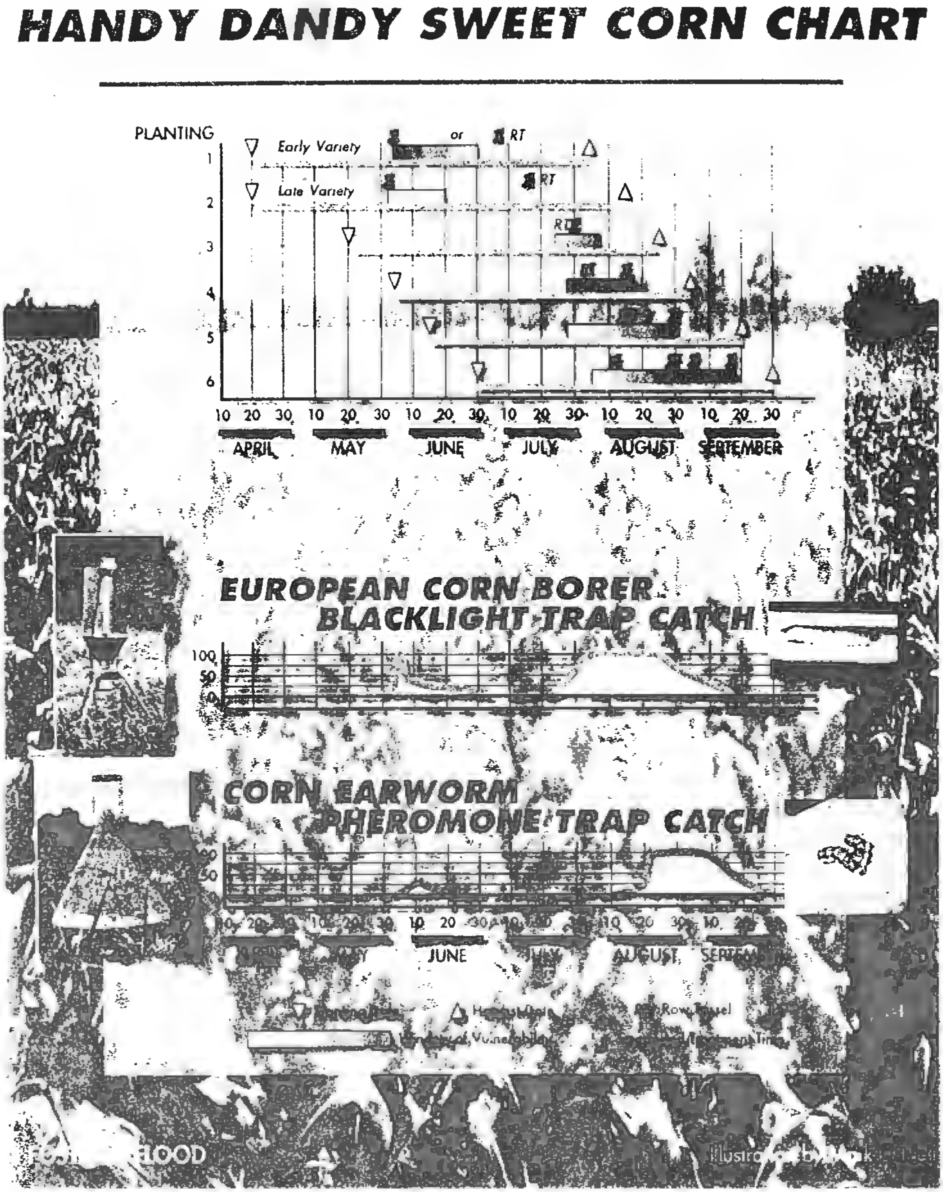

Figure 5. The Handy Dandy Sweet Corn Chart.

Résumé

Surveillance des Lépidoptères ravageurs dans la gestion des cultures légumières dans le centre Ouest des Etats Unis.

Le contrôle des ravageurs des cultures légumières exige une connaissance de l'interaction de la phénologie de la plante, du comportement de l'insecte et des niveaux des populations sur la culture. La grande étendue homogène du centre Ouest des Etats Unis permet de réaliser des prédictions saisonnières sur la base des modèles de temps stables et du mouvement des masses d'air. A niveau biologique, il y a 4 jours de différence pour 1° de latitude, 5° de longitude et 400 pieds d'altitude en partant du Nord Est au printemps et l'inverse à l'automne. Dans le centre Ouest, la période de plantation du maïs doux et des petit pois s'étend d'avril à août pour une récolte entre juin et octobre. Le petit millier d'hectares cultivés en légumes est entouré de millions d'hectares de maïs et de soja. Les insectes peuvent se disperser à partir de ces grandes cultures sur les cultures légumières. C'est la gestion des niveaux de populations et des modèles de dispersion qui font que notre système est unique. Les évaluations commerciales et les petites parcelles d'essais ont déterminées les caractéristiques d'une lutte par application d'insecticides courants pendant toute la saison sur plusieurs localisations. L'information est utilisée pour varier le taux et l'intervalle des applications et déterminer la période de traitement. Le doublement du taux d'insecticide augmentera la protection et les résidus de 3 à 5% tandis qu'un doublement de l'intervalle entraînera une perte de 10 à 30%. La fin des traitements, 20 jours avant la récolte, n'améliore pas la lutte dans les champs commerciaux. Ces facteurs ne donnent qu'une fenêtre étroite pour les traitements. La connaissance des ravageurs, des cultures et les outils de traitement ont permis de réduire significativement les coûts des traitements exigés pour produire une production légumière de haut rendement et non contaminée.

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Characteristics of IPM in vegetable crops in Hungary

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Abstract: Apart from controlling the polyphagous and host-specific pest insects that cause severe damage to vegetable crops in Hungary, considerable emphasis is now being placed on establishing systems that depend more on preventing pest attacks. Two ways that this is being achieved is by the production of healthy planting material and by controlling the important virus vectors. A characteristic of vegetable growing in Hungary is that the numbers of both native and introduced pests found in crops is still increasing. In addition to directly controlling these pests, further work is needed to improve all aspects of crop hygiene. Pest and disease control should not be based solely on applying conventional pesticides but should make full use of pest forecasting, selective biopesticides and mass-reared beneficial arthropods. The programs of management for reducing crop losses should also make full use of the biological information available about pest behaviour, and the contributions from both plant resistance and cultural control. Modern agriculture requires the management program to produce sustainable systems, of which two of the key components are crop protection and the provision of adequate nutrient supplies for the growing plants.

Key words: IPM, selective biopesticides, crop hygiene, plant resistance

Résumé

Caractéristiques de la protection intégrée (IPM) des cultures légumières en Hongrie.

Outre la lutte contre les insectes ravageurs polyphages ou spécifique qui provoquent des dégâts sérieux en culture légumière en Hongrie, un effort considérable est actuellement fait sur les systèmes qui sont davantage basés sur la prévention des attaques des ravageurs. Deux voies ont été développées, et sont achevées : l'une est la production de matériel planté sain et l'autre contrôle les vecteurs des virus importants. Une des caractéristiques des légumes cultivés en Hongrie est que le nombre des ravageurs trouvés, qu'ils soient d'origine locale ou introduit, est encore en augmentation. De plus pour contrôler ces ravageurs, d'autres travaux sont nécessaires pour améliorer tous les aspects de l'hygiène de la culture. La lutte contre les ravageurs et les maladies ne devrait pas être basée sur l'application conventionnelle d'insecticides mais devrait utiliser les avertissements, les bio pesticides et l'élevage d'arthropodes bénéfiques. Les programmes de surveillance pour la réduction des pertes des cultures devraient aussi utiliser à plein l'information biologique disponible sur le comportement des ravageurs et sur les contributions qui traitent de la résistance des plantes et de la lutte culturale. Une agriculture moderne exige des programmes de conduite des cultures pour des systèmes durables, dont deux des composantes clés sont la protection des cultures et l'approvisionnement en complément nutritif adéquat pour la croissance des plantes.

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Aspects of crop protection in the integrated production of field vegetable crops in Sweden

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Abstract: Integrated Production of field vegetable crops was started in Sweden in 1992 by the Vegetable Growers' Organisation. General guidelines as well as crop-specific recommendations have been produced for carrots, cole, onion and lettuce crops to be sold as fresh-market produce. As much as 60% of the vegetable acreage in Sweden is included in this IP-project. For crop protection in IP, ecologically safe methods have priority and special attention is given to: 1) minimising pesticides usage, 2) improving food safety and 3) protecting the grower's working environment, three strategies that fit well into Integrated Pest Management. The guidelines place the emphasis on the use of crop rotation, resistant cultivars, biological control, treatment thresholds, forecasting systems, warning systems, selective pesticides and band sprayers. The Swedish vegetable growers have difficulties, however, in implementing many of these recommendations because of economic constraints, the lack of relevant research results and insufficient advisory service. At present, the status of crop protection in IP-vegetables can be defined as: Good Agricultural Practice combined, whenever possible, with supervised control.

Key words: Integrated production, guidelines, carrots, kale, onion, lettuce

Introduction

Swedish field vegetables are grown on 6,570 ha by 1,424 growers. An additional 10,000 ha of peas are produced by the industry, for freezing and canning. Apart from peas, the largest other areas cropped with vegetables are 1,840 ha of carrots, 1,380 ha of cole crops (white/red cabbage, cauliflower, broccoli, Chinese cabbage and swede), 850 ha of onions and 660 ha of iceberg lettuce (Anonymous 1997). Organically-grown vegetables are produced on about 10% of the total acreage.

A project on the "integrated production" of field vegetable crops was started in Sweden in 1992 by the Vegetable Growers' Organisation. Integrated production of field vegetables was defined as a farming system in which

- ecologically safe production methods have priority,
- the use of pesticides and fertilisers are minimised,
- food safety has priority,
- the grower's working environment is improved,
- the production is controlled.

The IP project was considered to be of crucial importance to the future of Swedish vegetable production, as it was expected that products from integrated production from other European countries would soon be imported. Therefore, the Swedish vegetable producers could not afford to be complacent. Both general guidelines and crop specific recommendations were produced. These were, more or less, in agreement with similar projects for IP–vegetable crops grown in other European countries. Advisors were educated and 3-day basic courses were provided for growers, followed by shorter updating courses and field excursions that were done throughout the whole country. The growers can be certified as

IP-growers once they have fulfilled the appropriate course of education, and provided they agree:

1) to follow the guidelines and recommendations,
2) to document all steps in their production practices and
3) to submit their documentation for inspection, whenever required.

The inspections have been done by an independent organisation since 1995. In 1996, 60% of the acreage of vegetables for the fresh market were grown using the integrated production approach. The main reason for the high uptake by the growers is due frankly to the demands from the market. In 1995 the biggest buyers, led by the main supermarkets ICA and SABA, announced that in future they will buy only vegetables from growers who are certified IP-producers.

In "Guidelines for Integrated Production of Field Vegetable Crops", established by the Swedish Vegetable Growers' Organisation, recommendations are given for the whole farm as well as for specific crops. Whenever possible, mandatory recommendations are given, but these tend to be few in numbers, as the aim is to make the overall recommendations attainable by as many growers as possible. It is stressed, however, that integrated production is a dynamic process in which the rules and recommendations are being tightened gradually towards environmentally-safer methods.

Crop protection in IP

Vegetables for the fresh-market, as well as for processing, have to be of high quality and meet the EEC standards. With respect to crop protection, it is stated that "damage by pests and diseases, contamination of the produce by insects, is not permitted" (Anonymous, 1995). Pesticide residues must not exceed the Swedish maximum residue limits set by the Swedish National Food Administration. The IP-Guidelines state also that ecologically-safe production methods should be given priority, the use of pesticides should be minimised, food safety should be given priority and the grower's working environment should be improved. Crop protection, therefore, has a central role in the concept of IP.

***General rules and recommendations for crop protection in IP vegetables*:**

- A pest management strategy should be worked out before the onset of the season to ensure that preventative, as well as direct, control measures are considered.

Preventative measures

- The growing site should be selected so that crops in neighbouring fields do not act as host plants for potential pests.
- Crop should be rotated to avoid increasing the pressure from pests and diseases.
- Tests for soil borne diseases/nematodes should be used (if available) to avoid fields with high risk.
- Priority should be given to cultivars with resistance to diseases and pests.
- Seed and seedlings should be healthy and of high quality.

Direct control measures

- Warning/forecasting methods for pests and diseases must be used (when available) and the crop should be monitored regularly for the presence of pests and diseases. Threshold levels should be used to reduce chemical applications by avoiding treating on a routine basis.

- Biological, genetical and cultural control should be given priority over systems relying on pesticides.
- When the use of pesticides is unavoidable, the product chosen should offer effective plant protection but also be as safe as possible to humans, animals, beneficial insects, and the environment.
- The dose of the chemical applied should be minimised by using an appropriate application technique (i.e. band spraying).

Crop specific rules and recommendations have been produced for carrots, cole, onion and iceberg-lettuce crops in which the above guidelines are applied.

Crop protection in IP-vegetables – the reality

Carrots

Preventative measures

Location of growing site: Carrots are grown throughout Sweden but the main production areas are concentrated in the south and central regions. It is possible to escape attack by the carrot rust fly (*Psila rosae*) if the growing site of the carrots can be restricted to open windy fields, as this pest prefers sheltered field, particularly fields surrounded by hedges. In forest/woodland areas, the chance of finding exposed windy fields is small and in areas with coniferous vegetation it is impossible to escape attack by the carrot psyllid, *Trioza apicalis*. This pest overwinters on spruce and other coniferous trees and migrates into carrot fields in the spring. The chance of escaping pest attack is greater if fields can be selected from areas larger than a single farm. This is possible when carrots are grown on contract and this aspect becomes part of the overall production strategy.
Crop rotation: Although it is recommended that carrot crops should be included in rotations that avoid the build-up of specific weed, pest and disease problems, no actual recommendations are given. Growers are aware of such risks and generally rotate their crops. Information is still needed on the impact of crop rotation on storage diseases (i.e. on the most prevalent storage rot *Rhizoctonia carotae*), nematodes and difficult species of weeds.
Soil tests: There are none available for detecting any of the carrot pathogens.
Choice of cultivars: No resistant cultivars are used by the growers.
Seed and seedlings: All carrots are drilled and the seed available is of high quality.

Direct control of pests

Forecasting/warning, thresholds: Monitoring and forecasting systems, based on yellow sticky traps, are available for the carrot rust fly. Similar systems based on pheromone traps and records of temperature/precipitation are available for the cutworm (*Agrotis segetum*) (Esbjerg at al 1988; 1996). Both systems are available commercially and no insecticide treatment is allowed in IP-carrots unless it is based on these forecasting methods. For other carrot pests, such as the carrot psyllid, treatments should be made only after careful field inspection. As no threshold values have been developed, control with insecticides starts as soon as the pest is observed.
Biological control: No biological control agent has proved effective in carrot production.
Application technique: Band spraying has the potential to reduce the amounts of pesticide applied, especially when the carrots are small, for weed control and for control of the carrot psyllid. This technique, however, is used by few growers.

Safe pesticides: Selection of pesticides, which in IP should be restricted to ecologically - safe products, is in reality made by the National Chemical and Inspectorate in Sweden. A narrow range of pesticides is registered for use in field vegetable crops, all of which are considered to be minor crops.

Direct control of diseases

Control of diseases with fungicides should be restricted to IP crops of carrots in which rots are expected when the crop is subjected to cold storage. Ewaldz (1997) has shown, however, that the fungicides available for disease control in carrots, iprodion and vinclozolin (banned after May 1996), have limited effect. Although infections of *Sclerotinia sclerotiorum* can be reduced by these fungicides, the same chemicals are ineffective against the major disease, *Rhizoctonia carotae*, and many other storage rots. Our information concerning the biology and control of the complex of storage-rot pathogens found in the field and in carrot stores is insufficient.

Cole crops

Preventative measures

Location of growing site: Cole crops are grown throughout the country but the main area of production is centred towards the south of Sweden. The possibility of being able to select sites to avoid pest infestations is small, particularly when the site has to be selected from within the same farm. In the south of Sweden, the commonly grown oil-seed rape (canola) is a host plant for the cabbage root fly (*Delia radicum*), the cabbage aphid (*Brevicoryne brassicae*) and for pollen beetles (*Meligethes* sp.). Crops of spring-sown rape also support the first generation of the swede midge (*Contarinia nasturtii*). All four pests can migrate from the rape crops to the surrounding fields of cauliflower, broccoli, heading cabbage etc. Another example, occurs when vegetable cole crops are grown in forest/woodland areas, as in such situations it is impossible to avoid infestations of capsids (especially *Lygus rugulipennis*) that move in from the surrounding vegetation.

Crop rotation: Allowing 5 – 6 years between brassica crops is recommended for reducing the risk of clubroot (*Plasmodiophora brassicae).* This recommendation is a necessity in high-risk areas, whereas rapidly-maturing cole crops are grown at much shorter intervals, even in continuous cropping systems, on soil types in which the risk of clubroot is low. Crop rotation is not mandatory, as it is not yet a pre-requisite for IP-certification.

Soil tests: One is available for the detection of clubroot, but it is seldom used by vegetable growers.

Choice of cultivars: Cultivars with some resistance have been documented but the growers do not give these characters priority.

Seed and seedlings: Seed and seedlings of high quality are available. Most cole crops are transplanted.

Direct control of pests

Forecasting/warning, thresholds: The warning system for the cabbage root fly, which is based on the egg-traps as used in Denmark (Bromand, 1988) cannot be used in Sweden for timing the application of insecticide treatments. The insecticides (clorfenvinphos & diazinon) registered for controlling the cabbage root fly, must be applied either at sowing or planting, thus restricting their use as a preventative treatment or with a required 70 day interval between treatment and harvest which is too long for any practical purpose. Warning methods/thresholds for other pests of cole crops have not been developed for use under

Swedish conditions. Instead, control measures are applied following regular field inspections which, in reality, means that insecticides are often applied at the first sign of a pest. Insecticides often have to be applied early to obtain acceptable levels of control.
Biological control: *Bacillus thuringiensis*, which is applied to control lepidopterous larvae, is the only biological control agent which is both successful and accepted in the production of field vegetable crops, especially cole crops.
Safe pesticides: Selection of pesticide is made by the National Chemical Inspectorate, which has restricted the range of pesticides registered for use in field vegetables.
Application technique: Reducing the amounts of insecticide applied can be achieved by a combination of precision and transplanting to control the cabbage root fly. The high cost of the machinery restricts its use to the large-scale producers. Band-sprayers are seldom used in brassica crops, despite their potential to reduce drastically the amounts of pesticide applied in many cases. Seed treatment is another technique with a potential to reduce pesticide use, but has not yet been used to replace sprays for any brassica pest.

Direct control of diseases

Using fungicides to control diseases should be restricted in IP to cabbage crops grown for cold storage and to Brussels sprout, kale and Chinese cabbage crops produced in the late autumn. The information available on the importance of diseases is poor, however, being restricted largely to describing the range of possible pathogens and how they are affected by the few permitted fungicides.

Onion

Preventive measures

Location of growing site: Onion production in Sweden is concentrated in the south of the country and on the Island of Öland. Within a farm, the incidence of soil-borne diseases determines the fields suitable for onion production.
Crop rotation: A rotation of at least 4 years is recommended for the production of onion crops. Once a field is infected with white rot, *Sclerotium cepivorum*, a period of 8 - 10 years is required before a new onion crop can be grown. In the intensive onion producing areas, crop rotation is essential if crop losses due to soil-borne diseases are to be reduced. When stubby root nematodes (*Trichodorus/Paratrichodorus* spp) are present, the IP-Guidelines recommend that other host plants should not be included in the rotation. However, the host-plant range of these nematodes is extremely wide and so the chance of obtaining effective control by relying solely on crop rotation is low (Banck, 1997).
Soil test: Although a soil test is available for assessing the risk from nematodes, it is rarely used. No test methods are available for soil-borne diseases.
Choice of cultivars: Resistance is not yet available for any of the major pests or diseases.
Seed and seedlings: Most onion crops are direct drilled. The seeds available currently are of high quality.

Direct control of pests

Forecasting/warning, thresholds: Few insect problems occur in onion production in Sweden. The onion fly seldom reaches pest status and thrips are controlled only in severe cases. As no thresholds are available, the decision to apply an insecticide is based on common sense.
Biological control: No biological control agent has yet proved effective in onion production.
Safe pesticides: Selection of pesticide is made by the national Chemical Inspectorate, who restrict the range of pesticides that are registered for use in field vegetables.

Application technique: Band-spraying has the potential to reduce the amounts of pesticide sprayed, especially for treatments applied when the plants are small. It is used, however, by only a few growers.

Direct control of diseases

Most crop protection inputs into onion crops are for the control of diseases, particularly downy mildew *Peronospora destructor*, which poses a serious threat to onion production in Sweden. The forecasting model DOWNCAST, developed by Jesperson & Sutton (1987) was modified for Swedish conditions (Forsberg, 1995) and was evaluated on a practical scale by three groups of growers. As the results from this approach were encouraging, the model will be adjusted in 1998-99 to a commercial situation using data collected locally from a HARDI Metpole weather station. Without the forecasting method, onion crops are sprayed with fungicides according to a routine schedule.

Iceberg lettuce

Preventative measures

Location of growing site: The production of iceberg lettuce is concentrated mainly in the south of Sweden. Land surrounded by poplar trees should be avoided, as such trees are the winter hosts for the lettuce root aphid (*Pemphigus bursarius*).

Crop rotation: Although the IP Guidelines recommend that crop rotation should be used to avoid an increase in disease pressure, nothing else is specified. However, growers who specialise in lettuce production often use continuous cropping without problems. The short time interval between transplanting and harvest could help to explain why problems are not greater.

Choice of cultivars: At the outset, cultivars with resistance to pests and diseases should be chosen. A resistance mechanism to downy mildew, *Bremia lactucae*, which was available for several years, was broken in 1996/97. During the 1998 season, no *Bremia*-resistant cultivars will be sold. However, two cultivars with resistance to the lettuce aphid, *Nasonovia ribisnigri*, will be available on the Swedish market from 1998 onwards.

Seed and seedlings: The major part of the iceberg crop is transplanted. It is important to be aware that infection by *Bremia* can occur at the seedling stage. Therefore, unless high hygienic standard can be guaranteed to produce healthy plants, chemical treatment can be justified at the seedling stage.

Direct control of pests

Forecasting/warning, thresholds: No forecasting methods or thresholds are available for the important pests of lettuce. The main pest problem in iceberg lettuce is aphids, of which the lettuce aphid, *Nasonovia ribisnigri*, is the most damaging. This species represents about 80% of the total number of aphids found on, and inside, heads of lettuce. Control is based on regular field inspections, and is justified as soon as aphids are found. The insecticides available have limited effects against the aphids and so repeated sprays are common. In growing areas in forest/woodland (outside the main production areas), capsid bugs can also reduce crop quality. No thresholds or effective control methods are available, repeated pesticide treatments do not give adequate control.

Biological control: No biological control agent has yet proved effective in outdoor Lettuce production.

Safe pesticides: Selection of pesticide is made by the National Chemical Inspectorate, who restrict the range of pesticides registered for use in field vegetables.

Application technique: Band spraying is used by few growers, even though it has the potential to reduce greatly the amounts of pesticide applied.

Direct control of diseases

When no resistant cultivars are available, downy mildew is the most severe disease affecting iceberg lettuce crops. According to the growers, the fungicide "Aliette" does not provide adequate protection when infection pressure is high. A provisional permit to use metalaxyl was given in 1997. The risk of developing resistance to this chemical has to be considered, as control is based usually on routine sprays. Other diseases seldom justify chemical control.

Other crops

No specific recommendations have been produced for the other vegetable crops, although the general recommendations are still valid. For the pests, mentioned above, which attack other crops, the forecasting/warning method can be of value. The forecasting system for *Agrotis segetum* is valid also for red beets and leek and the monitoring system for the carrot fly can be used also in celeriac, root parsley and parsnips.

Comments

Crop protection in IP-vegetables should be channelled towards Integrated Pest Management (IPM). The Guidelines for IP-production are rather broad. At present, few mandatory rules have been developed in the hope that this might encourage the maximum number of growers possible to take part in the IP-project. A demand for crop rotation, which should form the basis of the crop protection strategy, cannot be achieved in many instances, because of lack of suitable soils within given farms and for other economic reasons. Crop rotation, therefore, is only a recommendation. Forecasting/warning methods, that can be applied in Swedish vegetable crops are restricted currently to the methods available commercially for *Agrotis segetum* and the carrot fly, *Psila rosae*. As few threshold levels have been produced for use under Swedish conditions, applying chemical control as soon as pests are seen on the crop can be justified. For many diseases, preventative fungicide treatments have to be applied. Biological control agents suitable for field use in vegetable crops are, at present, restricted to *B.t.* The choice of pesticides should be restricted to those which are safe both to the environment and to humans. The grower, however, often has no choice, as the range of pesticides registered for use in vegetable crop is extremely narrow. In reality, the requirement in IP, that only legally-registered compounds can be used, is the same as for conventional production.

IP-crop protection has not yet reached the standard expected of IPM, but fulfils Good Agricultural Practice (GAP), as defined by Codex Alimentarius Commission (1986), and is supervised as far as possible. The demand of documentation for all crop production procedures is one of the most obvious difference for growers, compared to what they did previously. Although control of the necessary documentation has been organised, this aspect needs to be improved if the credibility of the IP project is to be enhanced.

The way towards IPM is set: The growers' own organisation has established rules and recommendations for the production of vegetables and has the intention of tightening them towards environmentally safer methods as, and when, such methods are developed.

Routines for controlling the documentation and for educating farmers have now been organised. The intention of IP is in line with the goals set by the Swedish government. To raise the IP-concept to an IPM standard will require both an increase in applied research and an effective advisory service.

Résumé

Aspects de la protection des cultures en production intégrée des cultures légumières en suède.

La Protection Intégrée (IP) des cultures légumières de plein champ a commencé en Suède en 1992 à l'initiative de l'Organisation des Producteurs de Légumes. Des recommandations générales, ainsi que pour des cultures spécifiques, ont été rédigées pour la carotte, le chou, l'oignon et les cultures de laitues qui doivent être vendu comme produit frais sur les marchés. Presque 60% des surfaces légumières en Suède font partie de ce projet d'IP. Pour la protection des cultures en IP, les méthodes écologiquement sans risques ont la priorité et une attention spéciale est donnée à : 1) l'usage minimal des pesticides, 2) l'amélioration de la sécurité alimentaire et 3) la protection de l'environnement de travail des producteurs, trois stratégies qui s'accordent bien à la lutte intégrée des ravageurs (IPM). Les recommandations mettent en avant l'utilisation des rotations culturales, des cultivars résistants, de la lutte biologique, des seuils de traitement, des systèmes de prévision, des systèmes d'avertissement, de la sélection des pesticides et des pulvérisations en bandes. Les producteurs de légumes suédois ont cependant des difficultés dans la réalisation de la plupart de ces recommandations en raison des contraintes économiques, le manque de résultats de recherches pertinentes et de l'insuffisance des services de conseil. Actuellement, le statut de protection des cultures en IP légumes peut être défini comme une Bonne Pratique Agricole combinée quand c'est possible à une lutte dirigée.

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Investigations on the supervised control of *Thrips tabaci* in leek & onion crops

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Abstract: *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) is a major pest in onion and leek crops in Germany. The practical implementation of supervised control of pests and diseases in these crops was tested in a co-operative research project that involved the plant protection service. Intensive investigations were made on the impact, biology and control of *Thrips tabaci*. The field trials, which were located in different parts of Germany, included 45 that were done on experimental stations and 59 that were done in growers' fields. The trials were done between 1994 to 1996. The results indicated that supervised control of thrips could be introduced successfully into practice and help considerably to reduce the number of insecticide treatments. Adoption of this system did not result in loss of yield or quality, when compared to the routine program of pesticide use. It was shown also that thrips damage in onions has been over-estimated by growers in the past. The main period of crop infestation by *Thrips tabaci* in Germany extended from July through to October and reached peak numbers in August. A high correlation was found between the percentage of infested plants and both the number of thrips per plant and the percentage of damaged leaf area. Data on crop loss assessment collected during this series of trials indicated that both onions and leeks had a very high capacity to compensate for damage done by thrips.

Introduction

The onion thrips, *Thrips tabaci* Lindeman (Thysanoptera, Thripidae), is the most important pest of leek (*Allium porrum* L.) and onion (*Allium cepa* L.) crops in Germany. In leek, damage caused by *T. tabaci* can lead to lower prices or even rejection at market. In practice, it is often not easy to recognize an attack of this pest sufficiently early to judge its commercial implications. As a consequence, insecticides are often applied on a routine basis. This is not in accordance with the official rules. Since 15 September 1986, the German plant protection law has stated that pesticides should be applied only after a pest threshold has been exceeded. Investigations to develop such thresholds were introduced by Hommes (1992) and Hommes *et al.* (1994). Within the overall research project, thresholds for all of the important pests and diseases of onions and leeks were tested (Table 1). However only the work on *T. tabaci* is described in this paper.

To gain more information about the population dynamics of thrips, especially their flight activity and life-cycle, leek plants were examined on a regular basis. Using such results, attempts were made to determine whether pesticide treatments could be restricted solely to the period of crop infestation (Kahrer, 1992). The competitiveness of the crop to tolerate damage by pests was studied by analyzing the associated data collected on crop loss assessment.

Table 1. Action thresholds for pests and diseases in leek and onion crops.

	Onion	Leek
Leek moth	10 % infested plants	10 % infested plants
Thrips	50 % infested plants	50 % infested plants
Botrytis		60 % infected plants
Downy mildew		start of infection
White rot		start of infection
Rust	10 % infected plants	
Purple blotch	20 % infected plants	

Materials and methods

The investigations were done in the main *Allium* growing areas in Germany between 1994 to 1996. Altogether 55 trials were done in leek and 49 in onion crops (Table 2). Simple farm demonstrations consisted of an untreated plot, a plot subjected to routine pesticide use and a plot with pesticide applied according to the action thresholds shown above.

Table 2. Number of trials at farms and experimental stations and size of area cultivated in Germany.

Number of trials	Leek	Onion
On experimental fields	24	21
On grower fields	31	28
Cultivated area (1994)	2375 ha	5773 ha

More complex trials on experimental stations were used to compare different control strategies. On the experimental stations, the treatments were set-out in a randomized block design. In such studies, field sampling started one week after the leeks had been transplanted and once the onion plants had reach the 2-leaf stage. Samples were taken every two weeks. In grower fields, sub-samples of 5 plants were inspected at 10 positions distributed regularly across each plot. On the experimental stations, 5 replications were taken with 10 plants in each. All plants were inspected carefully for insects and for any signs of pests or diseases. Because the sampling was based on presence or absence of thrips, only the numbers of plants infested was recorded. However, the area of leaf damaged was estimated also for each plant. The "routine" plot was treated with insecticide every two weeks and the threshold plot was treated after the threshold values had been reached, or exceeded. At harvest, 100 plants from each treatment were weighed, trimmed for market and checked individually both for insects and damage. Damage by thrips was graded on a scale of 1 to 5 (Table 3). In addition plant samples were taken from an untreated area. These samples (15 plants) were taken weekly as long as possible until winter. The number of living thrips, adults and larvae was recorded from each plant to obtain further information about the population dynamics of *T. tabaci*.

To monitor flight activity, two white water-traps were placed into each field. The traps were emptied once a week from April until November. All insects collected from the plants and from the water-traps in 1994 were stored in alcohol and embedded subsequently in polyvinyl-lactophenol. Thrips specimens were identified using a microscope and Priesner's key (1964). The two species of thrips found in the plant samples were *T. tabaci* (70 % to 100 %) and *Frankliniella tenuicornis* (up to 30 %). Trap catches consisted of many different thrips species. The thrips caught in the traps during 1995 and 1996 were embedded and identified in the same way as the thrips collected from the plant samples.

Table 3. Classifications for quality of leek and onions in this project and on the market class.

Scale for leek	% damaged leaf area.	market
1	≤ 1% → top quality	class I
2	> 1 % and 5 % → good quality	class IIa
3	> 5 % and 10 % → still marketable	class IIb
4	> 10 % → marketable after trimming (up to 3 leaves)	
5	> 10 % → not marketable	class III
Scale for onions	**% bulb surface with faults and damages**	
1	free from damages → top quality	class Ia
2	≥ 20 % with faults and damage → good quality	class Ib
3	≤ 33 % with faults and damage → marketable	class II
4	≤ 50 % with faults and damage → ≥ 33 % of the upper skin damaged → still marketable	class III
5	≥ 50 % with faults and damage and ≥ 33 % of the upper skin damaged → not marketable	

To test if the period of insecticide application can be limited to different time periods, the crops were sprayed either in July, August or September. Insecticide treatments were applied every 5 days during each of the three months. These strategies were compared with an untreated and a routinely-treated plot. These treatments were placed in a randomized block design.

The competitiveness of the crop to tolerate damage was studied in another randomized block. Crop loss consisted of defoliation of parts of the plant, in particular the foliar tissue. Every two weeks, 1 % to 60 % of the terminal portion of each leaf was removed.

Results and discussion

Supervised control - onion

The typical situation in an onion field is shown in Figure 1. The development of thrips infestation was similar in all treatments. The insecticide applications had little effect on the overall level, as during the main flight period of *T. tabaci* new infestations occurred continuously. The threshold value of 50 % plant infestation was exceeded at the end of the cropping period. However, at this point the bulbs were matured and the leaves were beginning to die. Therefore, by this stage insecticide applications were no longer necessary. Only covering the crop with a net could delay the thrips infestation by preventing the thrips from reaching the plants.

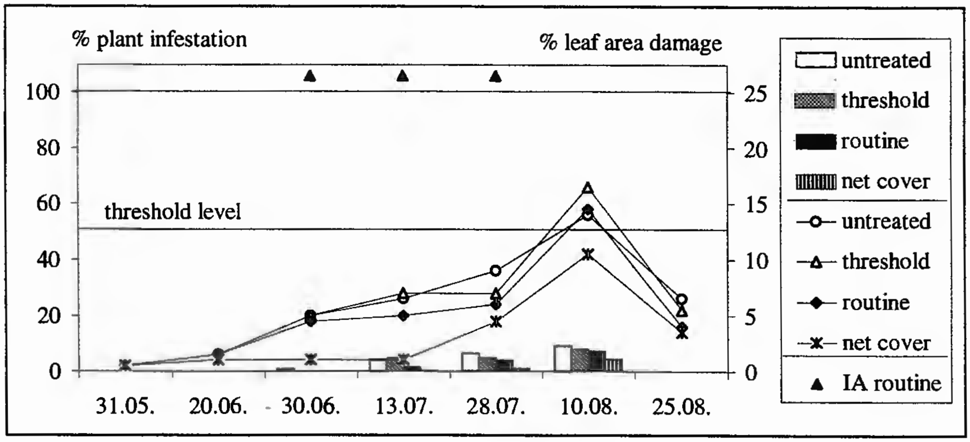


Figure 1. Development of infestations of thrips populations in onion crops together with the percentage of damaged leaf area, on the threshold-, routine- and untreated-plots (Trial at the FBRC, 1995).

Although yield seemed to be higher after routine applications, the effect was not significant (Figure 2). The most cost-effective system (yield less costs for pest control) was obtained from the untreated plots. The results of 18 experiments indicated that the importance of *Thrips tabaci* damage to onion crops had been overestimated in Germany. This was a surprising result, because the growers' association indicated before the start of the project that thrips would be the main pest, as they cause severe yield losses in onion crops and therefore growers have to apply sprays frequently throughout the season.

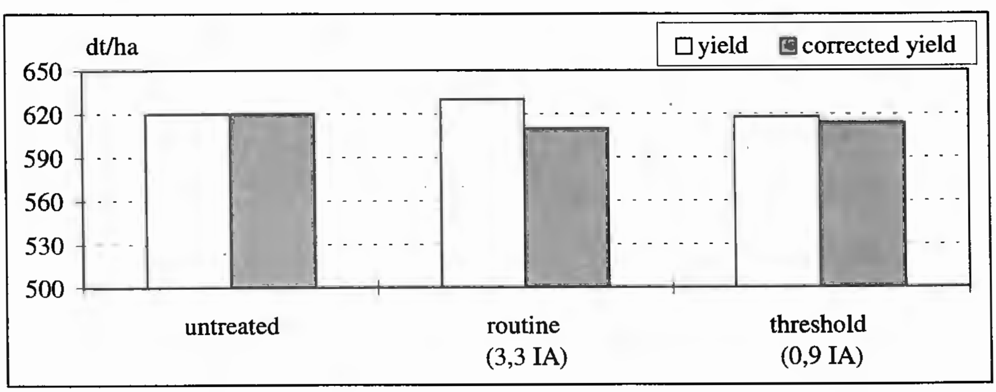


Figure 2. Average yield of 18 experiments on supervised control of thrips in onion crops (corrected yield = yield less costs for pest control).

Supervised control - leek

The development of the infestations of thrips in leek crops differed from that in onion crops (Figure 3). Usually leek plants are either already infested when planted into the field, as in the experiment presented, or they become infested within days once field temperatures increase at the end of August. In the experiment conducted at Bonn, nearly all plants were infested. The damaged leaf area reached 9 % of the total plant. Consequently plant quality declined. In the routine plot, 6 insecticide applications were made, whereas in the threshold plot 3 applications were sufficient to keep the infestation level below the threshold value. At harvest, the results from 9 trials showed that there was a significant difference between the untreated and the treated plots with respect to the quality and yield of marketable leeks (Figure 4). There was no visible difference in quality and yield between the leeks from the threshold and routine plots, although a third less insecticide was applied to the threshold plots. Successful supervised control of *Thrips tabaci* was demonstrated in practice and resulted in a significant reduction in the amounts of insecticide applied to onion (60 %) and leek (30 %) crops in Germany.

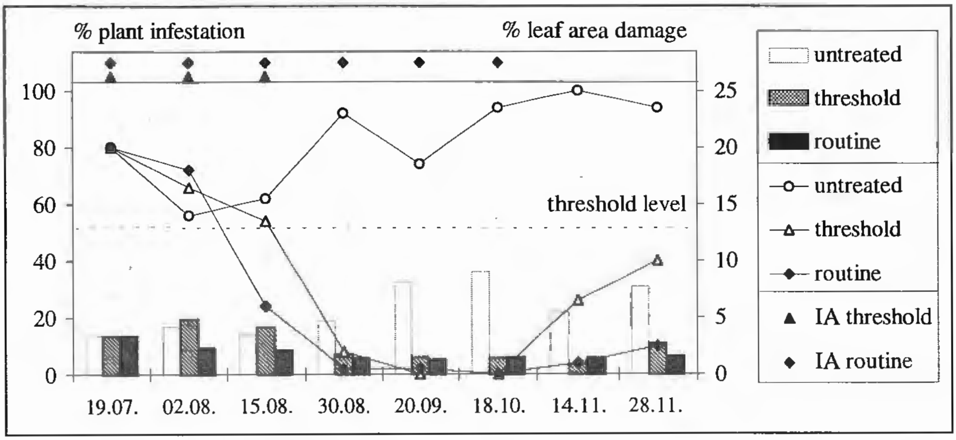
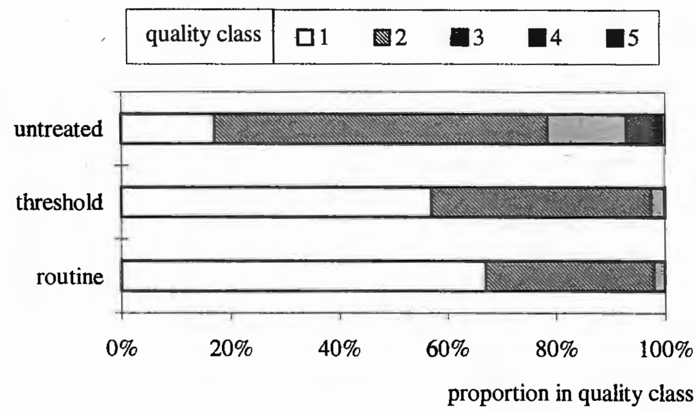


Figure 3. Development of infestations of thrips populations in leek crops together with the percentage of damaged leaf area on the threshold-, routine- and untreated-plots (Trial at Bonn, 1994).

Population dynamics

Catches from the white water-traps (Czencz, 1987) indicated that there was some flight activity of *T. tabaci* in May and June as well as in October and November (Figure 5). The main flight activity started in July and lasted until September, with a peak in August. The flight in Germany was later than that recorded in Austria (Kahrer, 1992 & 1994) and corresponded better with the timing recorded by Imhof *et al.* (1996) and Villeneuve *et al.* (1996). However, the high numbers recorded by the latter authors were not found in Germany. A maximum of 50 *T. tabaci* were found from 300 thrips caught in one trap during



average weight/plant g	IA
304	-
323	4,4
318	6,2

Figure 4. Results from the 9 experiments on the supervised control of thrips in leek crops.

one week. The flights of *T. tabaci* before and after the main period of flight activity appeared to be short flights to locate new resources.

The routine inspections indicated that the small leek plants were infested shortly after transplanting. In general, thrips have ideal conditions for development from July onwards due to the high temperatures that occur during the warm summer months. By the beginning of August, all plants showed signs of thrips damage and the numbers of thrips-larvae had increased to as high as 80 larvae/plant (Figure 6). This infestation level remained high until October and then declined with the decreasing field temperatures. The number of adult thrips remained low throughout the season and never exceeded 20 adults per plant until October. Probably during the summer many adults migrated from the plants (Sites *et al.*, 1985). Once the temperature decreased, the thrips adults stayed to overwinter on the plant. A distinct reduction of adult numbers, as a result of predation during the summer months, was never observed. The only predator recorded, *Aeolothrips intermedius*, fed on the thrips larvae. Damage to plants increased on young plants in August and reached its highest level at the end of August. As soon as the thrips population started to decline in the autumn, the relative damage was reduced by the plants continuing to grow.

Because of the presence-absence sampling used in these trials, it is of interest to determine whether there is a relationship between the percentage of infested plants and the population density of thrips-larvae per plant (Figure 7 a). Such a relationship could be used in practice when the incidence of thrips is low. In order to show this clearly, the relationship is limited to a density of about 10 thrips-larvae per plant (Figure 7 b). The prediction is reliable until 80 % of plants become infested. The threshold value of 50 % plant infestation that was used, ensures that the thrips population remains low and control measures are still beneficial. Furthermore, the data were analyzed to determine whether there was a relationship between the percentage of infested plants and the leaf area damaged by thrips (Figure 7 c). The actual relationship at low incident levels, was similar to the relation described below. The results indicate that if the thrips population can be maintained below the threshold the damaged leaf

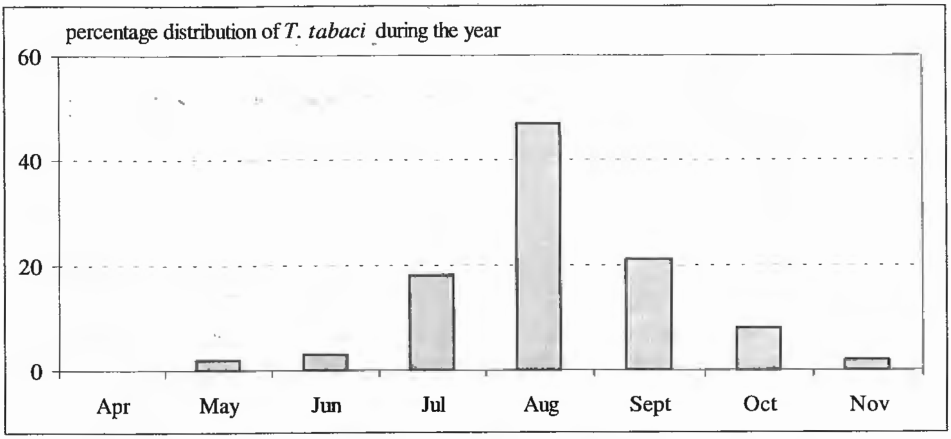


Figure 5. Catches of *Thrips tabaci* in white water-traps (summary of all locations with traps in leek during 1994-1996).

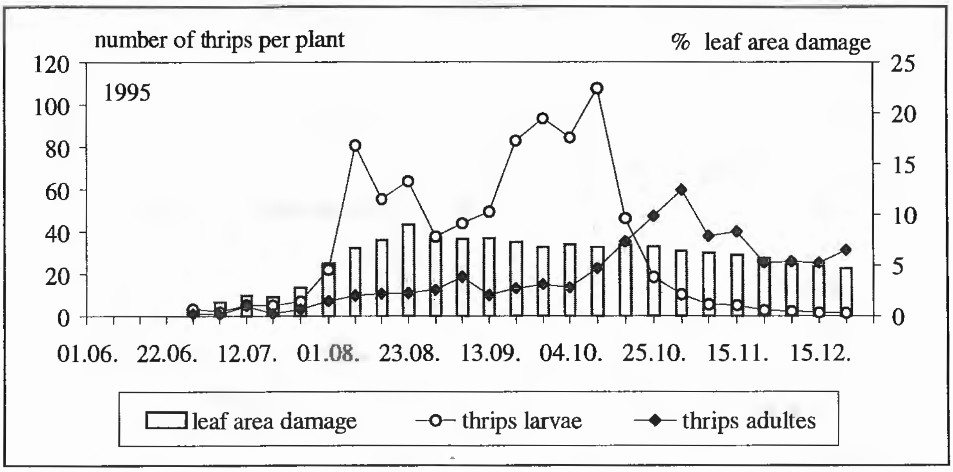


Figure 6. Infestation by thrips and damaged leaf area on leek crops on untreated plants (mean of three sites 1994, Lower Saxony).

area will not exceed 2 %. This will ensure that both the quality and marketable yield will be good. Since a clear relationship between the number of thrips per plant and the damaged leaf area could not be found, leek plants will have to be sampled regularly. Crop damage reflects the results of thrips activity rather than the actual stage of infestation and freshly-infested plants rarely show any damage symptoms (Theunissen & Legutowska, 1991).

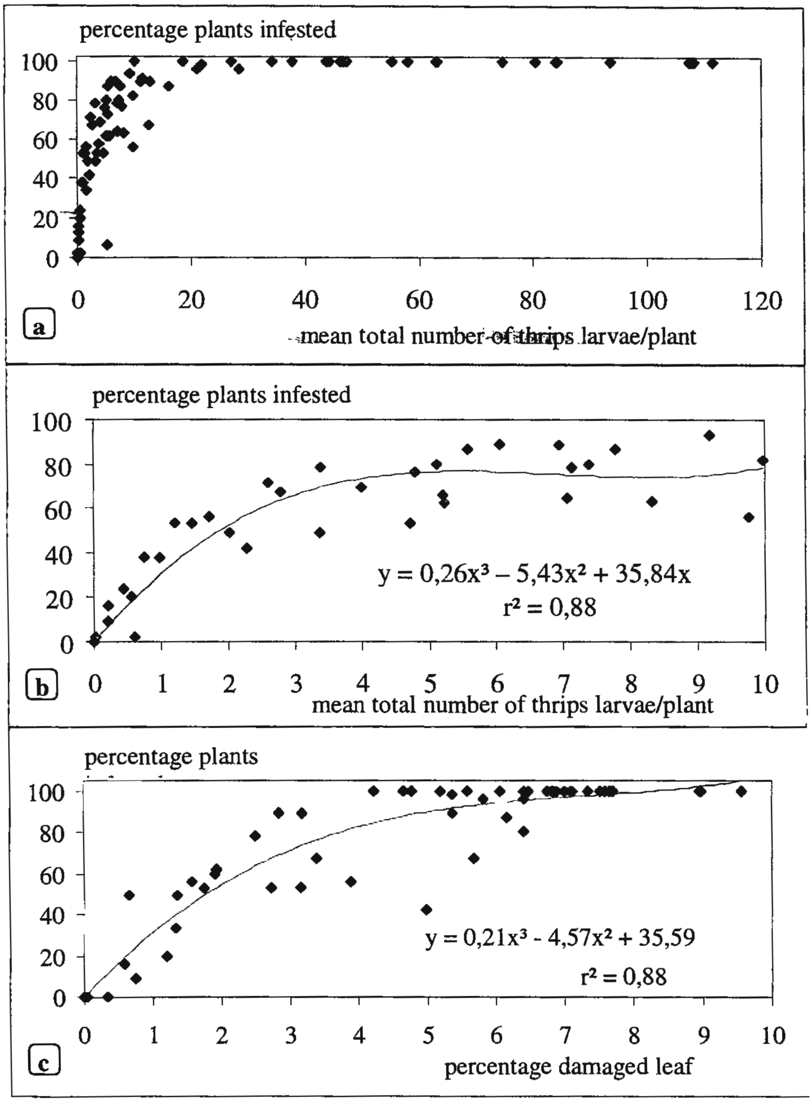


Figure 7. a) The relationship between the percentage of infested plants and the numbers of thrips-larvae per plant. b) The same relationship for the data from 0.1 - 10 thrips-larvae/plant. c) Relationship between the percentage of infested plants and the leaf area damaged by thrips.

Control periods

In this experiment, although the infestation began slowly, nearly all of the plants in the untreated plots were infested during the first two weeks of August and the infestation remained high until harvest (Figure 8). The levels of infestation in the routine pesticide plots stayed at a low level, except for a short increase at the beginning of August when the thrips invaded the crop. Insecticide applications in the first period (July), before thrips invaded the crop, were applied too early to be effective. The graph of the data from this treatment was similar to that of the data from the untreated plot. Applications made in the third period (September), were too late to have any significant influence on the thrips population. However, it was possible to keep the infestation at a low level, similar to the infestation in the routine pesticide treatment, when the insecticides were applied in the second period (August) during the time of main period of flight activity by the thrips. Thrips invading the crop later were not able to build-up a sufficiently large population to cause severe damage. These results were reflected by the percentage of leaf area damage at harvest (Figure 9). Although damage occurs in all treatments, applications made both in August and in the routine pesticide treatment produced fewest symptoms.

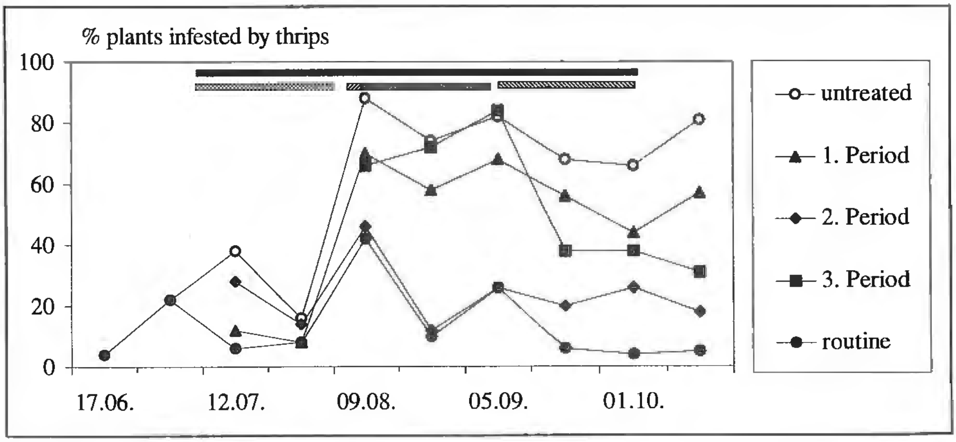


Figure 8. Infestation by *Thrips tabaci* in leek after periodical control in July, August or September compared with an untreated- and a routinely-treated plot.

Crop loss assessment

In the case of onions, many of the results concerning the influence of thrips on yield were contradictory. In the current experiments, onions were relatively insensitive to defoliation. They tolerated, or even produced compensatory growth, when 1 % and 5 % was cut off the top leaf on a regular basis (Figure 10). Even defoliation of 10 % had no significant effect. In practice, damage caused by thrips in most onion fields was lower than 10 %. Additionally, as thrips do not destroy the complete leaf tissue, but only the upper cells, the affected parts can still photosynthesize. Further experiments (Richter, in preparation) indicated that the sensitivity of onions, and an associated reduction in yield, was at its peak during the bulbing stage. These results are similar to those of Kendall & Capinera (1987).

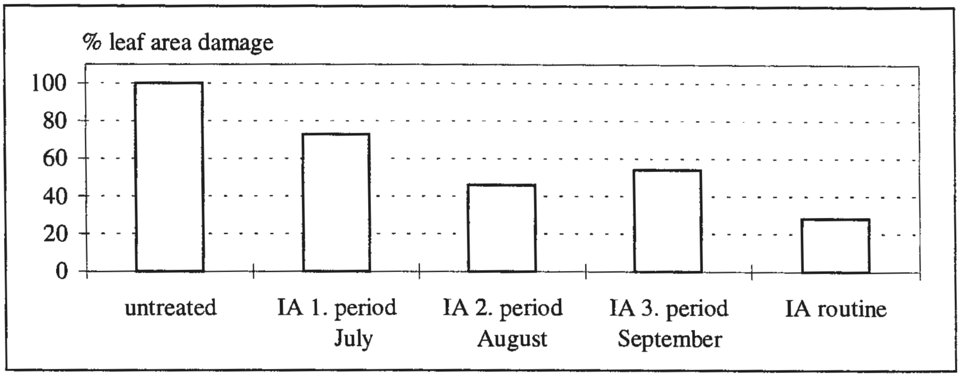


Figure 9. Comparison of leaf area damaged by *Thrips tabaci* in leek after periodical control in July, August or September with an untreated- and routinely-treated plot.

In conclusion, the method of supervised control tested in these experiments was simple, effective and reliable. Infestation level in both leek and onion crops could be determined by the growers in a short time. The threshold value for thrips, based on 50 % plant infestation, ensured that insecticide applications were made at the appropriate time and without any risk to the quality or quantity of the harvested produce. The results indicated also that the time of insecticide applications in leek can be limited to the period of flight activity of *T. tabaci*, and in onions to the time during bulbing, when onion plants are most susceptible to thrips damage.

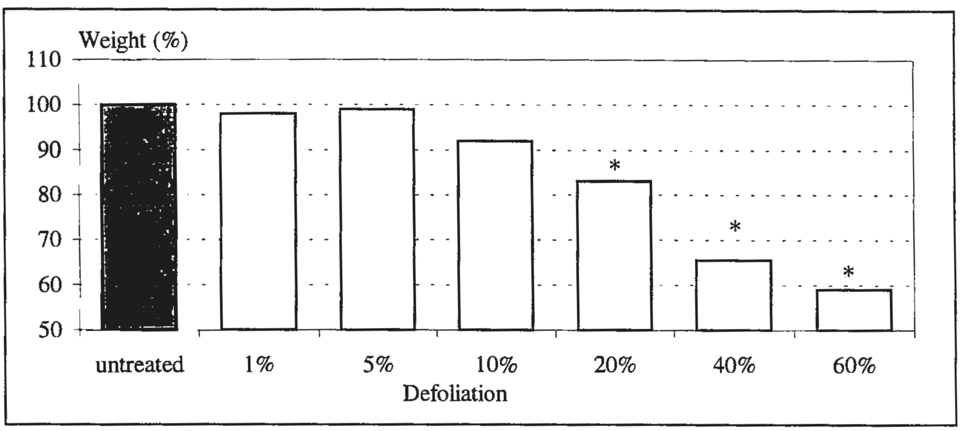


Figure 10. Effect of mechanical defoliation on yield of onions. Weight of dry onions at harvest, experiments of 1995 and 1996, cv. Marco, *marks significant differences to untreated (Dunnett-Test).

Résumé

Recherches sur la lutte surveillée de *Thrips tabaci* en parcelles de poireau et d'oignon.

Thrips tabaci Lindeman (Thysanoptera : Thripidae) est un ravageur important des cultures de poireau et d'oignon en Allemagne. La réalisation pratique de la lutte surveillée contre les ravageurs et les maladies de ces cultures a été testée dans un projet de recherche en coopération avec les services de la protection des végétaux. Des recherches intensives sont faites sur l'impact, la biologie et la lutte de *T. tabaci*. Les essais aux champs, qui sont localisés dans différentes parties de l'Allemagne, au nombre de 45 dans des stations d'expérimentation et de 59 dans des exploitations agricoles. Ces essais ont été réalisés entre 1994 et 1996. Les résultats indiquent que la surveillance des thrips pourrait être introduite avec succès dans la pratique agricole et permettraient ainsi de réduire le nombre des traitements insecticide. L'adoption de ce système ne modifierait ni la perte ou la qualité de la récolte comparativement au programme classique d'utilisation de pesticides. On montre également que les dégâts de thrips dans les cultures d'oignon étaient surestimés par les producteurs dans le passé. La principale période d'infestation des cultures par *T. tabaci* en Allemagne s'étend de juillet à octobre et atteint son maximum en août. Un forte corrélation a été trouvée entre le pourcentage de plantes infestées et le nombre de thrips par plante ainsi que le pourcentage de surface de feuille attaquée. Les données sur l'estimation des pertes en culture collectées au cours de cette série d'essais indiquent que les oignons comme les poireaux ont une forte capacité à compenser les dégâts dus aux thrips.

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Integrated Control in Field Vegetable Crops
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Encouraging biological control as a component of pest and resistance management in cabbage in the Midwestern United States

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Abstract: Widespread resistance to several classes of insecticides by the diamond-back moth (*Plutella xylostella* (L.) (Lepidoptera: Plutellidae) and an increasing reluctance on the part of growers and consumers to use or consume toxic insecticides, have combined to create an urgent need for a more balanced approach to integrated pest management in cabbage crops with reduced reliance on broad-spectrum insecticides. A pest management program was developed and implemented in the Midwestern US, which utilized pest specific *Bacillus thuringiensis* (Bt) insecticides to manage lepidopteran pests at pre-determined threshold levels, thereby preserving the activity of natural controls. This approach has been successful for the lepidopteran complex particularly in early- and mid-season crops when diamond-back moth and the imported cabbage worm (*Pieris rapae* (L.) (Lepidoptera: Pieridae) are predominant with a reduction in pesticide applications from 8-10 to 1-3 per season. Resistance management for the diamond-back moth can be achieved by substitution of broad-spectrum chemicals with Bt in concert with natural control. It is anticipated that the potential for resistance in the imported cabbage worm and the cabbage looper (*Trichoplusia ni* (Lepidoptera: Noctuidae) has also been reduced. Future pest specific insecticides such as Spinosad® and tebufenozide have also been evaluated for inclusion in such programs. Non-lepidopteran pests in cabbage fields should be managed where possible using tactics that do not have an adverse impact upon the natural enemies of pest Lepidoptera. These could include pest specificity through timing for cabbage maggot, trap crops for flea beetle, predation for aphids and host-plant resistance for thrips.

Key words: Biological control, *Bacillus thuringiensis*, *Plutella xylostella*, *Pieris rapae*, *Trichoplusia ni*

Introduction

Cabbage and other cole crops grown in the Midwestern and Eastern United States are susceptible to a wide range of pest insects. Tolerances to pest damage for both processing and fresh market cole crops are extremely low and the industry has relied heavily on insecticides to manage pest insects. Multiple applications of insecticide are used frequently to achieve the necessary level of control. The bulk of these sprays are targeted at the lepidopteran complex consisting of the diamond-back moth (DBM) *Plutella xylostella* L., the imported cabbage worm (ICW) *Artogeia* (=*Pieris*) *rapae* L. and the cabbage looper (CL) *Trichoplusia ni* (Hubner) (Eastman *et. al* 1995).

Widespread resistance to several classes of insecticides by the DBM in North America (Shelton *et al.*, 1993) and the annual transportation of transplants infested with resistant DBM into Midwestern growing areas, has reduced significantly the efficacy of insecticide-based control programs. Concurrently, federal pesticide regulations introduced in 1997, which are targeted at reducing the use of toxic broad-spectrum materials, are limiting the availability of insecticides, particularly on small acreage crops such as the crucifers. As a result, growers can no longer rely on insecticidal control alone and there is a critical need for broad-based IPM programs, which incorporate both biological and cultural methods of pest control.

Fortunately, the pest complex associated with crucifers, particularly the lepidopteran insects, has a high potential for natural biological regulation (Mahr *et al.* 1993). Studies on naturally-occurring biological control on cabbage in Wisconsin (Quick 1984 & Steffen 1997) have shown repeatedly that high levels of parasitism are present in the absence of broad-spectrum insecticides. DBM is most heavily parasitized (60% – 90%) with *Cotesia glomerata* (L) (Hymenoptera: Braconidae) and *Pteromalus puparum* (L) (Hymenoptera: Eulophidae) being the predominant parasitoids. The CL is the least parasitized species in the complex (10–30%) but several parasitoids are present including *Trichogramma* sp. (Hymenoptera: Trichogrammatidae), *Copidosoma floridanum* (Ashmead) (Hymenoptera: Encyrtidae) and *Voria ruralis* (Fallen) (Diptera: Tachinidae). In addition to naturally-occurring parasitoids, several additional species are available commercially and these could be released to augment natural control. Such species include *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae), *Trichogramma evanescens* (Hymenoptera: Trichogrammatidae), *Cotesia rubecula* (Marshall) (Hymenoptera: Braconidae) and *Cotesia marginiventris* (Cresson) (Hymenoptera: Braconidae).

To realise the potential of natural or augmented bio-regulation of the lepidopteran pests of cole crops, growers must avoid disrupting the complex of natural enemies. Biorational insecticides such as *Bacillus thuringiensis* (var. kurstaki and var. aizawi), which are lepidopteran-specific, can play a key role in this regard by allowing growers to manage lepidopteran pests to meet the stringent, often damage-free, standards of the industry using a combination of natural control and biorational insecticides.

A biologically-based IPM program for brassica crops

In the Midwestern United States, a biological IPM program has been developed for cabbage, which utilises pest specific *Bt* in combination with biological and cultural controls. This approach has been successful in enabling participating growers to reduce pesticide applications from 8–10 broad-spectrum applications to 1–3 specific applications (Del Monte Corp., personal communication). The IPM program (Wyman, 1992) includes the three following aspects:

Monitoring

Pest populations are monitored weekly throughout the season, using non-destructive plant counts, (Sears *et al.* 1985) to provide the basis for *Bt* application. Lepidopteran pests are counted in the larval stage. To facilitate scouting for growers, caterpillars are not identified to species. Instead, insecticide applications are based on the percentage of plants infested by any species of caterpillar in the pest complex. When available, adult monitoring by pheromones (DBM, CL) provides a useful adjunct to scouting. Monitoring of beneficial insects and levels of parasitism are not used currently in the commercial IPM program but should be used, whenever practical, to assess the potential for natural bioregulation or augmentation.

Thresholds

All *Bt* applications involve a threshold based on percent infestation weighting the three lepidopteran species equally (Shelton *et al.* 1983, Sears *et al.* 1985, Eastman *et al.* 1995). Thresholds are dynamic and vary with the growth stage of the plant. For fresh-market cabbage, treatment decisions are made at infestations of 10% (seed bed), 30% (transplanting to cupping), 20% (cupping to early heading) and 10% (early to mature head). For processing cabbage, where heads are trimmed, the thresholds may be raised by 5%–10% during the transplant to heading stages. Broccoli and cauliflower are treated at 10% in the seed bed, 50% from transplant to early curd formation and 10% from first curd to maturity.

Conservation of natural enemies

Parasitoids and predators are protected currently from disruption by using *Bt*-insecticides. This approach is particularly effective in early and mid-season (May–August) in the Midwestern USA when DBM and ICW are the predominant lepidopteran pests. In late season (Sept–Oct) CL populations frequently increase to damaging levels and, as *Bt* is less effective against large CL instars, a broad-spectrum insecticide may be required in such situations. Several new biorational insecticides are being developed for use on cole crops in the United States. These materials are characterised by low mammalian toxicity and a high degree of specificity to lepidopteran pests. The various modes of action exhibited by the new biorational materials make them particularly important in managing resistance to *Bt*, which has now been reported in the Southern US. Biorational insecticides, which have been evaluated and shown to have limited toxicity to beneficial insects include: Spinosad, tebufenozide and chlorfenapyr.

Although the lepidopteran pest complex causes the most severe economic damage to cole crops, other pest species occur sporadically. These sporadic pests may require management and it is essential that the approaches used do not disrupt the biological component of the main lepidopteran program.

The cabbage maggot (CM) *Delia radicum* (Wiedemann) is frequently an early-season pest of cole crops in the Midwestern US. Although several species of ground beetles are known to regulate CM populations, biological control rarely provides commercially-acceptable levels of control and, in situations where CM populations are high, a soil insecticide may be required. Thermal unit models are effective in predicting CM oviposition (Eckenrode & Chapman 1971) and provide growers with the opportunity to time accurately insecticidal applications. Accurate timing, together with precise placement of material, combine to minimise any adverse effects of such applications on populations of beneficial insects.

Flea-beetles, *Phyllotreta* sp., are occasional early-season pests of cole crops, and can be particularly damaging to seedling plants. Biological controls are uncommon and insecticidal application can disrupt the establishment of lepidopteran parasitoids. In cases where treatment is required, a short-persisting material should be chosen to minimise any disruptive effects. An experimental approach, using a trap crop of Indian mustard, has shown promise as an alternative to applying insecticide.

Onion thrips, *Thrips tabaci* Lindeman are often pests on certain cabbage varieties in July and August. No effective natural enemies are known and on susceptible varieties, insecticidal treatments are required occasionally. Since such sprays would be extremely disruptive to lepidopteran natural enemies, thrip-tolerant varieties should be used when implementing a biological IPM programme for Lepidoptera.

The cabbage aphid, *Brevicoryne brassicae* (L) is occasionally a late -season pest of cole crops. An extensive complex of beneficial insects, including the aphidiid parasitoid, *Diaretiella rapae* (Mc.Intosh), and several aphid predators, usually hold populations at sub-economic levels in the absence of disruption. Thus, cabbage aphid biological control is favoured in a biological IPM program for cabbage. When natural enemy populations are not sufficient to prevent damaging aphid populations, a short persisting insecticide may be required. Specific aphicides such as pirimicarb and pymetrazine, which are being developed for use on vegetable crops, are ideally suited for maintaining aphid populations at non-damaging levels, while encouraging natural control.

Cabbage and other crucifers are thus excellent candidate crops for the establishment of biologically-based IPM programs. Such programs rely on selective insecticides such as *Bt* to maintain lepidopteran pest populations below damaging levels, while conserving natural enemy populations to provide long term biological regulation. The potential to further improve bio-intensive IPM in these agroecosystems is enhanced by the availability of commercially-reared natural enemies for augmentative release and new pest specific biorational insecticides, which are currently in development. The diverse mortality factors that interact to manage pests in such systems will also contribute significantly to the management of insecticide resistance.

Résumé

L'encouragement à la lutte biologique est une composante de la lutte contre les ravageurs et leur résistance dans les cultures de choux dans le centre Ouest des Etats Unis

L'extension de la résistance de plusieurs types d'insecticides utilisés contre la teigne des crucifères (*Plutella xylostella* L. Lepidoptera : Plutellidae) et un refus croissant de la part des producteurs et des consommateurs à utiliser ou à consommer des produits insecticides, se sont combinés pour créer une urgente nécessité d'avoir une approche plus équilibrée de la lutte contre les ravageurs du chou et une réduction du spectre des produits insecticides utilisés. Un programme de lutte contre les ravageurs a été développé et mis en place dans le centre Ouest des Etats Unis qui utilise comme insecticide spécifique *Bacillus thuringiensis* (Bt) pour lutter contre les Lépidoptères ravageurs sur la base de seuils de tolérance pré déterminés, préservant ainsi l'activité des auxiliaires naturels. Cette approche a été un succès pour le complexe des Lépidoptères particulièrement sur les cultures précoces et de demi saison quand la teigne et les pièrides (*Pieris rapae* (L.), Lepidoptera : Pieridae) sont dominants avec une réduction du nombre d'intervention allant de 8-10 à 1-3 par saison. Le contrôle de la résistance pour la teigne peut être complété en substituant au large spectre d'insecticide le Bt en complément des auxiliaires naturels. On anticipe ainsi le potentiel de résistance qui pourrait être induit sur les noctuelles importées et les noctuelles locales (*Trichoplusia ni* Lepidoptera : Noctuidae) ont aussi été diminuées. Des insecticides spécifiques tels que le Spinosad® et le Tebufenozide ont aussi été évalués pour être inclus dans de tels programmes. La lutte contre les ravageurs autres que les Lépidoptères pourrait être organisée si possible en utilisant des tactiques qui n'aient pas d'impact contraire sur les ennemis naturels des Lépidoptères ravageurs. Cela pourrait inclure le ravageur spécifique tel que la mouche du chou, les plantes pièges pour les altises, la prédation pour les puçerons et les plantes non hôtes pour les thrips.

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Behaviour of Pest Insects

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Is the initial colonisation of leek by *Thrips tabaci* affected by intercropping with clover?

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Abstract: The reason why thrips populations are reduced when leek crops are undersown with clover are unknown. In this experiment, initial colonisation by the airborne *Thrips tabaci* populations was compared in leek grown in pots with and without strawberry clover, and which were later placed into which field plots of monocropped and intercropped leek. From the very beginning, colonisation rates in the intercropping pots were lower in comparison with the leek monocropping. After only four days, 70% of the newly-established thrips adults (almost all females) were found on the monocropped leek plants in the pots. Clearly, the leek/clover intercropping has attributes that reduce colonisation by thrips adults.

Key Words: *Thrips tabaci, Trifolium fragiferum, Allium porrum,* undersowing

Introduction

Undersowing vegetable crops with other plant species shows considerable promise for producing high quality crops without the use of pesticides (Theunissen & Schelling, 1997). However, the underlying mechanisms that contribute to the observed pest reductions have not yet been identified. This hampers the optimisation of the intercropping system, e.g. the search for the ideal vegetable/undersown crop combination and also its integration into existing cropping practices because of the uncertainty about its compatibility with current crop protection measures and agronomic practices.

We know that in leek plots undersown with different species of clover, that the numbers of thrips present are reduced considerably (Theunissen & Schelling, 1997). However, it is not known whether these differences result from a reduced initial colonisation, reduced survival and development or from a combination of the two.

Reduced colonisation in a host plant/clover intercropping system, that effectively prevented pest insect outbreaks, was found for cabbage aphid (*Brevicoryne brassicae*), and the cabbage butterfly (*Pieris rapae*), when cabbage plants were grown in white and red clover (Andow *et al.*, 1986). No data could be found for reduced colonisation in thrips in crop/clover intercropping combinations. Letourneau & Altieri (1983) suggested that reduced numbers of the Western Flower Thrips (*Frankliniella occidentalis*) in a squash/corn/cowpea intercropping system resulted from predation by *Orius sp.* and not by variation in thrips colonisation when compared to squash monocropping system.

In this study, colonisation by *Thrips tabaci* was compared between leek (*Allium porrum* L.) cv. Tadorna, interplanted with strawberry clover (*Trifolium fragiferum*) cv. Palestine, and leek in monocropping.

Materials and methods

A combined field/pot plant experiment was done to assess the rate of colonization of leek plants by thrips. The leek plants were grown in pots with and without strawberry clover. These pots were placed into field plots of monocropped leek or leek intercropped with strawberry clover, for a period of four days in the first week of September.

The natural population of the onion thrips in the field was our source of infestation and during the test period the natural population of thrips was high. We started with potted plants that were free of thrips. This was achieved by treating the leek plants with Mesurol (methiocarb) one week before the pots were put out into the field. During the 4-day test period, the plants were checked daily for the presence of natural enemies.

Ten sets of 4 pot plants (A-J) equal in size and nitrogen concentrations in leaves and shafts were distributed over the field plots according to Figure 1. In the field, the distance between the rows was 55 cm while leek plants were placed 14 cm apart within the row. The distance between the four clover rows was 10 cm.

Each set of pot plants was placed 2 metres from the boundary of the field on the bare soil or in the clover and the distance between the pots was 2 meters. The treatments included a pot plant with clover (P+) or without clover (P-) in a field with (F+) or without (F-) clover. Four days after the start of the experiment the number of adult thrips were counted during a careful dissection of the plant material. Throughout the growing season, weekly observations were made of the populations of larvae and adults of *T. tabaci*. Five plants were selected at random from each plot. Each plant was examined leaf by leaf so that the numbers of thrips larvae and adults could be counted accurately. The data were analysed by ANOVA.

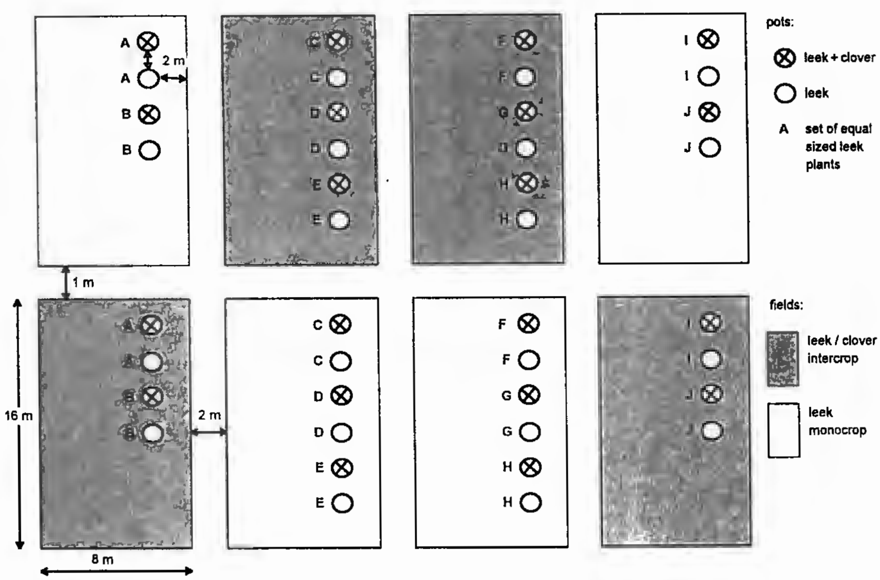

Figure 1. Diagram of distribution of 10 sets (A-J) of 4 equal-sized leek plants with or without clover over field plots with and without clover.

Results and discussion

In the field plots without clover the mean number of adults recorded from all of the leek plants in the pots (5.4 - Table 1) was more than twice as high as on all the leek plants in the pots containing clover (2.1 - Table 1, left column). Similarly, from the weekly counts it appeared that the number of thrips adults on the plants that surrounded the pot plants were higher in the field plots without clover than in the intercropping plots.

The numbers of *T. tabaci* adults counted on the leek plants in the pots without clover were higher than on the plants grown in pots with strawberry clover when placed into both the monocropped and the intercropped field plots (Table 1, right column). The results show clearly that during colonisation the thrips preferred the leek plants growing in pots in bare soil to the leek plants in pots growing in pots of strawberry clover. Even four days after the introduction of the thrips-free plants, more than 70% of the newly-established thrips adults (almost all females) were found on the leek plants growing in bare soil. Clearly, the leek/clover intercropping has features which reduce the number of thrips adults.

Table 1. Mean number of *Thrips tabaci* adults found on leek plants growing in pots of bare soil compared to the numbers found on leek plants growing in pots of strawberry clover. Differences were tested by ANOVA for all pots combined in the field plots, with and without clover, and secondly differences were tested per field treatment. Different letters indicate differences at $P<0.05$.

treatment	mean±s.e.		treatment	mean±s.e.	
pot plant in field without clover (F-)	5.4±1.3	a	pot plant without clover (P-)	7.8±2.3	a
			pot plant with clover (P+)	2.5±0.7	b
pot plant in field with clover (F+)	2.1±0.4	b	pot plant without clover (P-)	2.9±0.3	a
			pot plant with clover (P+)	1.6±0.2	b

The aim of this experiment was to test whether initial thrips colonisation differs between leek plants with and without clover undersown. Concerning the underlying mechanisms, we can say that during this short-duration experiment no predators and parasitoids were found in the leek plants growing in the pots. By using thrips-free potted plants and the short exposure time, possible actions of antagonists were reduced. We conclude, therefore, that the lower levels of thrips adults are due either to the direct effects of the clover during colonization or to indirect effects on the thrips adults through changes in the leek plant. The mechanisms described thoroughly by Altieri (1994) and Finch (1996), such as physical interference, visual camouflage, masking of host plant odours, altering host plant odours and taste, may all have played a role. These together with the mechanism of "appropriate/inappropriate landing" (Finch, 1996) will be examined in much greater detail elsewhere using another experimental set up.

Résumé

Est-ce que la colonisation initial du poireau par *Thrips tabaci* est affectée par la culture intercalaire de trèfle.

La raison pour laquelle les populations de thrips sont réduites lorsque les cultures de poireau sont associées à du trèfle est inconnue. Dans cette expérience, la colonisation initial par les populations aériennes de *Thrips tabaci* était comparée sur des poireaux cultivés en pot, avec et sans trèfle, qui sont placés plus tard dans des parcelles au champ en monoculture de poireau ou en culture intercalaire. Au tout début, les taux de colonisation dans les parcelles en intercalaire sont plus faibles comparativement aux parcelles en monoculture. Après seulement quatre jours, 70 % des adultes de thrips nouvellement installés (presque tous des femelles) sont trouvés sur les poireaux des pots placés en parcelle de monoculture. Clairement, on peut attribuer la réduction de la colonisation des thrips adultes à l'association poireau/trèfle.

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Possible reasons for the decline in carrot fly (*Psila rosae* (F.)) infestations in western Europe

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Abstract: A decline in infestations of carrot fly (*Psila rosae* (F.)) has been observed in The Netherlands and Switzerland during the last 15 years. In this paper, possible reasons for this decline are discussed. These include changes in cultural practices, the use of insecticide seed treatments and a shift from carrot varieties highly susceptible to carrot fly damage to types which possess partial resistance to the pest. In addition, pest monitoring is being used to determine the incidence and timing of carrot fly activity and to target chemical treatments more accurately. A knowledge of these changes and techniques should help growers in other countries to adopt new practices to reduce the severity of carrot fly damage.

Key words: *Psila rosae*, carrot fly, *Daucus carota*

Introduction

The carrot fly (*Psila rosae* (F.)) is the most severe pest of carrots (*Daucus carota* L.) and related umbelliferous crops in many temperate regions of the world. Damage by carrot fly larvae threatens crop production and even minor blemishes can render some crops unmarketable. Control of the carrot fly has been the subject of intensive research at Horticulture Research International and at several research institutes in The Netherlands and other countries in Europe for over 40 years (Hardman, Ellis & Stanley, 1985).

In 1990, it was apparent that the severity of carrot fly attack appeared to be declining in The Netherlands. An article published in Groenten and Fruit in The Netherlands entitled "The carrot fly has been on holiday last year", suggested that populations of this pest had declined (Schoneveld & Ester, 1993). Similar observations were made by workers in the UK, although this was not substantiated and does not appear to apply in the 1990's. Declines in carrot fly infestations have been noted before. For example, prior to the second world war, carrot fly was a severe pest of carrots in New York State (Glasgow, 1931) but then numbers declined to such an extent that it was not regarded as even a minor pest in the 1990's (C.J. Eckenrode, personal communication). No reason for the reduction of carrot fly populations in New York State has been substantiated, although certain research workers considered that the widespread use of organochlorine insecticides may have been responsible. However, in Europe and other parts of North America, where organochlorine insecticides were applied routinely to carrot crops for many years, no such decline in carrot fly infestations has been recorded.

There are numerous factors, both abiotic and biotic, which can reduce populations of a pest.

In this paper we examine aspects of crop production, chemical crop protection and use of partially-resistant carrot varieties and discuss their potential influence on the levels of carrot fly damage.

Crop production

Carrot fly survival and population increase are favoured by certain crop production methods such as the continuous cropping of land with carrots both in time and space, cropping in small fields provided with abundant shelter and hedgerow flowers, and storing carrots in the ground during the winter. It might be expected that populations of carrot fly would decline if these practices were avoided (Bleasdale, 1981). Prior to 1980, carrots were grown extensively in The Netherlands in the sandy soils of the coastal regions. Most farms were small, situated close to each other, and had many shelter belts. This shelter provided adult flies with abundant sources of food and protection. Carrots were first drilled in February with sequential sowings in spring and summer in the same or neighbouring fields. Therefore, at the time the first generation of carrot flies emerged in the spring there was an abundance of carrots on which the flies could lay their eggs. Furthermore, the sandy soil favoured survival of eggs, young larvae and also migration of larvae from root to root. In addition, as the soil was quick to warm up in spring, larval development was rapid. Carrots sown in the summer were traditionally stored in the ground during winter under plastic covers or straw, as most maincrop carrots are now stored in Britain. Such conditions in The Netherlands favoured the carrot fly.

In contrast to the situation described above, carrot production in The Netherlands in the late 1980's and throughout the 1990's has been concentrated on clay or peat soils on large farms operating strict crop rotation systems. The farms are well-separated and have few or no shelterbelts. The growers do not leave carrot crops in the ground during the winter. Instead the crop is harvested in early autumn and moved to purpose-built cold stores. Hence larval development in the autumn is stopped as soon as the crops are lifted. This truncates the development of the late generation of carrot fly and thus reduces the number of overwintering pupae which will give rise to the first generation of flies in the following spring. The soil types, particularly clay soils, and cropping in large fields with few shelter belts create conditions which affect adversely the survival of both carrot fly eggs and larvae. In addition, farmers rarely drill a second sowing of carrots in the same field and so there is little overlap between crops. These changes in crop production methods explain partly the observed decline in carrot fly numbers in The Netherlands.

Carrot varieties

The use of resistant varieties of a crop can result in a decline in pest numbers. It might be expected that the widespread use of partially-resistant carrot varieties would reduce carrot fly populations. At HRI Wellesbourne, host plant resistance to carrot fly has been studied intensively for the last 25 years. Approximately 400 carrot varieties have been screened against carrot fly and promising sources of resistance identified (Ellis, Hardman & Dowker, 1982a; 1982b; 1987; Ellis, Hardman, Jackson & Dowker, 1980; Ellis, Wheatley & Hardman, 1978).

Varieties that showed promising levels of resistance were re-tested at Wellesbourne and at other sites in Britain by the Henry Doubleday Association and at several sites in Europe under the auspices of the International Organisation for Biological Control (IOBC) Working

Group on Breeding for Resistance to Insect and Mites (Ellis & Hardman, 1981). The highest levels of resistance in cultivated carrot exist in the Touchon types, such as cv. 'Sytan', which were developed in the Nantes region of France (Ellis, 1992). The partial levels of resistance in cv. 'Sytan' provide a 50% reduction in the number of larvae and pupae developing on roots and a 50% reduction in larval damage (Ellis, Freeman & Hardman, 1985). The Touchon type has been a parent in the production of many of the leading varieties of carrot now grown in Europe. For example, cv. 'Nandor' has been very popular in The Netherlands and in the UK while cvs 'Primo' and 'Tip Top' have been grown widely in Switzerland. These are all varieties which have partially-resistant material in their parentage. Experiments have been done to investigate the effects of growing varieties possessing contrasting levels of host plant resistance with specific sowing and harvesting dates for the crop. Nine combinations of sowing and harvest dates provided marketable roots of `Sytan' compared with only three combinations of dates for a highly susceptible carrot variety (Ellis, Hardman, Cole & Phelps, 1987). The use of insecticides and partial plant resistance has been found to be additive. Thus, to achieve a marketable crop of the partially-resistant variety `Sytan' required one third of the dose of insecticide required to achieve the same levels of carrot fly control on a susceptible carrot variety (Thompson, Phelps & Ellis, 1994). Painter (1951) stated that resistant plants, which reduce a pest population by 50% in each generation, are ideal for reducing damage to below the economic injury level within a few generations. One of the characteristics of resistant varieties is their cumulative and persistent effects, which contrasts markedly with the more immediate effects of using insecticides. The combination of resistant varieties with biological control often leads to additive effects of the two control methods. In contrast, the use of insecticides often has adverse effects on natural enemies and this may lead to the resurgence of a pest, which then gives rise to even higher populations in the absence of natural control. Several examples exist of the long-term benefits of growing resistant varieties (Panda & Khush, 1995).

Prior to 1980, Amsterdam Forcing carrot varieties were grown extensively in The Netherlands in the coastal regions. These varieties were fast developing and many were susceptible to carrot fly attack. In other parts of The Netherlands, Berlicum and Flakkeese types of carrot, many of which were susceptible to carrot fly, were grown for fresh market. In the last 15 years, growers in The Netherlands have grown mainly bunched and topped Nantes-types, that possess partial resistance to carrot fly and which are harvested in early autumn. Although there is no quantitative evidence of a reduction in carrot fly larval damage, the change of carrot varieties now grown in The Netherlands, might be expected to lead to a decline in carrot fly numbers.

Twenty years ago in the UK, Autumn King and Chantenay types of carrot dominated the industry. An appreciable acreage of these carrot types were grown in different parts of Europe. Many of these varieties support large numbers of carrot fly larvae. However, the carrot industry in the UK is now dominated by Nantes types, many of which are partially-resistant to carrot fly attack. It might be expected that this change would reduce carrot fly populations in the UK but no decline has been evident.

This is probably because growers continue to over-winter their carrots in the ground and this leads to a build-up of damage and insects successfully completing their development, even on partially-resistant varieties.

Crop protection measures

Improvement in application techniques and timing of insecticide sprays (Phelps, Collier, Reader & Finch, 1993) could be expected to lead to a reduction in carrot fly numbers. In Europe prior to 1980, carrot fly was controlled mainly by the application of organochlorine insecticides such as aldrin, dieldrin and DDT at drilling and a range of other insecticides were applied mid-season to kill second generation flies. However, growers did not monitor carrot fly numbers and therefore mid-season sprays were often badly timed. The second generation of carrot fly attack was often severe. Since 1989, a higher proportion of the crop has been grown using insecticide-coated seed (Ester & Neuvel, 1990). In addition, a system for monitoring carrot fly using sticky traps has been introduced which enables growers to target sprays more accurately using a supervised control programme (Schoneveld & Ester, 1994; Ester & Schoneveld, 1996). In The Netherlands in 1995, 62% of the area cropped used a supervised scheme and although only 5 growers reported damage, it was at the 1% level. In 1996, about 60% of growers also used the supervised scheme for carrots grown at the time of the second and third generations of carrot fly. These practices are believed to have reduced greatly carrot fly populations in The Netherlands. In the French-speaking regions of Switzerland, especially in the Orbe Plane, carrot fly numbers have been recorded for many years using sticky traps. A reduction in carrot fly numbers on traps was recorded in 1983 and populations have not recovered since (J. Freuler, Personal Communication). Possible reasons for this decline include a series of warm, dry summers which adversely affect carrot fly egg and larval survival, strict crop rotation, more accurate sprays based on trap records and early lifting of crops based on pest threshold information.

Conclusions

Very little quantitative data have been published to support the hypothesis that carrot fly populations have declined in countries such as The Netherlands and Switzerland. However, research workers who monitor carrot fly numbers, who record carrot fly damage to crops and who liase closely with growers in these countries are in no doubt that a decline has occurred during the last 15 years. From the discussion above, it is clear that several different aspects of carrot production can influence the survival of carrot fly. It is likely that a combination of factors has reduced populations in The Netherlands and Switzerland. In the UK many crop production methods have changed. However, the fact that growers still over-winter their crops in the ground probably negates any benefits from using partially-resistant varieties.

Résumé

Les raisons possibles du déclin des infestations de la mouche de la carotte (*Psila rosae* (F.)) dans l'Ouest de l'Europe.

Un déclin des infestations de mouche de la carotte a été observé en Hollande et en Suisse durant ces 15 dernières années. Dans ce papier, les différentes raisons de ce déclin des infestations de mouches sont évoquées : la présence de plantes dont la sensibilité est réduite aux attaques de mouches, types possédant une résistance partielle aux ravageurs. De plus, la méthode d'avertissement utilisée pour déterminer l'incidence et la période d'activité des mouches et programmer l'utilisation de traitements chimique est plus précise. La connaissance de ces changements et de nouvelles techniques pourraient aider les producteurs dans d'autres pays à adopter ces nouvelles pratiques pour réduire la sévérité des attaques de mouche de la carotte.

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Monitoring carrot fly populations, and the effect of low soil moisture on the mortality of eggs and first-instar larvae

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Abstract: All stages in the life-cycle of the carrot fly were monitored in the field in 1997. The flies preferred to oviposit on carrots that had not been exposed previously to carrot fly rather than on carrots already damaged by larvae. Due to high temperatures during August, larvae of the second generation initially suffered a high rate of mortality but recovered soon after. Under controlled conditions, carrot fly eggs were killed by either very low soil moisture contents (< 14% field capacity), or by very wet soil. The mortality of first-instar larvae was also high at low soil moisture contents.

Key words: *Psila rosae*, egg samples, larval samples, Tullgren funnels

Introduction

Carrot fly (*Psila rosae* F.) mortality, resulting from abiotic factors such as temperature, soil moisture and humidity has been recorded from the field for many years (Petherbridge *et al.*, 1946). However, few attempts have been made to quantify the effects of such factors (Burn, 1984; Overbeck, 1985; Finch & Vincent, 1996). With the recent development of accurate pest forecasts (Collier *et al.*, 1992; Phelps *et al.*, 1993), it should now be possible to include data on natural pest mortality to define even more accurately the most appropriate times to apply insecticide. This paper describes the techniques developed at HRI Wellesbourne to identify the most susceptible stage in the life-cycle of the carrot fly, and preliminary experiments to quantify how low soil moisture affects the survival of carrot fly eggs and first-instar larvae.

Materials and methods

Population Monitoring

At HRI Wellesbourne, a plot of carrots (cv. Narbonne) was sown during April 1997. To keep the carrot fly pressure as high as possible, none of the carrots were treated with insecticide. As soon as the seedlings started to emerge from the soil, half of the plot was covered with agricultural fleece to protect the plants from the first-generation carrot fly attack. At the end of July, between the first and second fly generations, the carrots that had been covered previously, were uncovered. This gave the second-generation flies a choice of carrots; a) those that had sustained attack from the first-generation and which appeared yellowed and unhealthy as a result of larval damage, and b) those that were as yet undamaged.

The larval and pupal stages of the carrot fly population were monitored from April to October by taking twelve soil cores (10cm diameter x 15 cm) twice-weekly. All three larval instars and pupae were extracted from the soil cores using a method based on Tullgren funnels (Finch and Vincent,1996). In addition, carrot fly eggs were also sampled during the second-generation by removing a section of soil (20cm x 10cm x 2cm depth) from along a carrot row and floating the eggs out in water. Eggs were picked off using a fine paintbrush and examined under a stereo-microscope to determine the status of each egg (full, hatched or desiccated). Adult flies were monitored using Rebell yellow sticky traps placed throughout the plot. The type of sampling used for each insect stage is summarised in Table 1. All sampling was done on the carrots that had been exposed, and those that had not been exposed, to the first-generation attack.

Table 1. Carrot fly sampling methods.

Stage	Type of sample	Extraction method	Frequency
Eggs	surface soil sample	flotation in water	12 twice-weekly
Larvae	soil core	heat extraction (Tullgren funnels)	12 twice-weekly
Pupae	soil core	flotation in water	12 twice-weekly
Adults	yellow sticky trap		6-10 twice-weekly

Soil moisture as a mortality factor

Carrot flies were collected from the field from a large cage placed over a section of a carrot plot (cv. Narbonne). Approximately two-hundred flies were placed in a perspex cage (37 x 37 x 37cm) under controlled environment conditions (18°C, L:D 16:18) and fed with 10% sugar solution, water and a yeast/soya flour mix. An oviposition site, which consisted of a 9cm Petri-dish with a carrot top (leaves and 2cm root) buried slightly in moist sieved field soil, was placed in the cage for 48 hours. The eggs were floated out of the soil, picked off with a fine paintbrush, and counted onto black filter paper.

a)Eggs

The effect of soil moisture was determined by mixing various amounts of water with known quantities of sieved field soil (a sandy loam) (Table 2). The field capacity (FC) of the soil was calculated to be 30g water/100g soil (wet weight) and so subsequent soil moistures were expressed as a percentage of the field capacity. The base of 9cm Petri-dishes were filled with each of the soils (3 or 4 replicates of each treatment). Either 10 or 20 eggs were placed on the surface of the soil and covered lightly with a thin layer of soil of the same moisture level. The dishes were sealed and placed at 20°C for 8 days, after which the eggs were floated out and examined to count how many had hatched.

b) First-instar larvae

To obtain larvae, carrot fly eggs were kept on moist filter paper at 20°C for seven days. The newly-hatched larvae were picked up carefully with a fine paintbrush and transferred to 15cm diameter pots of carrots (cv. Autumn King) which had had the top 5cm of compost (John Innes No.2) removed and replaced with composts of different moisture contents. Three water contents were used; wet, dry and very dry (100%, 8% and 4% FC respectively). Twenty larvae were added to each pot, and each treatment was replicated eight times. The two dry treatments were not watered for four days, but were then kept moist on capillary matting in a glasshouse for the duration of the development period. After seven weeks, the pots were washed out and the floating organic matter and pupae were poured onto a fine-meshed sieve so that the pupae could be picked off.

Table 2. Sieved field soil (sandy loam) and water combinations used to create a range of soil moisture contents.

Soil	Soil/water mixture	% FC
1	500g dried in microwave for 2 minutes	5
2	500g allowed to dry naturally	14
3	500g + 20ml water	31
4	500g + 40ml water	41
5	500g + 80ml water	55
6	500g + 120ml water	71

Results

Population monitoring

During the second carrot fly generation, peak egg-laying occurred over a very short period around 8 August on both the damaged and undamaged carrots (Figure 1). Very high numbers of eggs were laid - up to six hundred per metre of row, equating to approximately eight eggs per carrot. However, there was a clear difference in the number of eggs laid on the two types of carrot. Over twice as many eggs were laid on the undamaged carrots than on the damaged carrots during most of the egg-laying period.

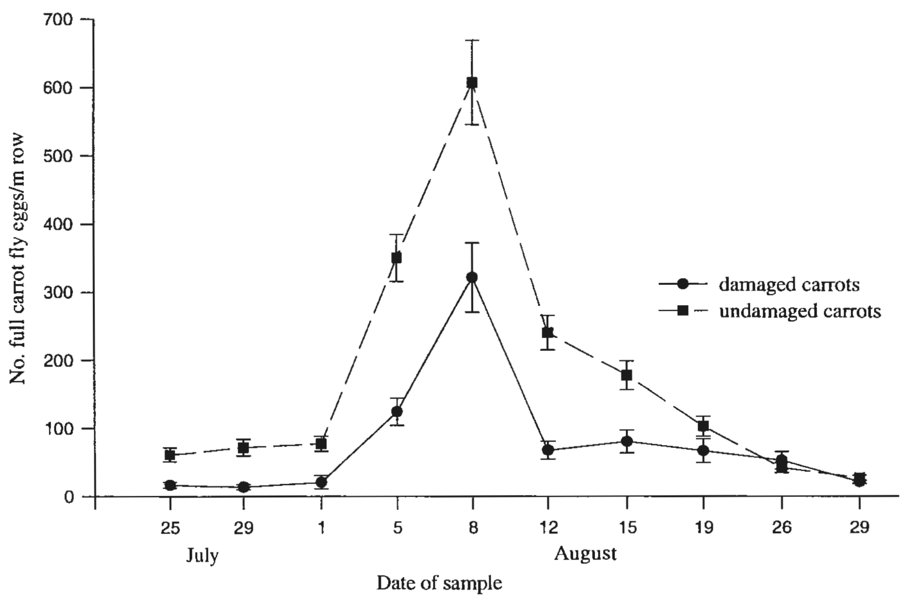

Figure 1. The number of full carrot fly eggs recovered/m of crop row from damaged and undamaged carrots during the second fly generation. Error bars = standard errors.

Monitoring larval numbers showed that when compared to the first generation (Figure 2a), mortality of first-instar larvae was high during the second generation (Figure 2b). The first generation displayed the expected sequence of larval development, with the peak numbers of each instar occurring in succession. However, in the second generation, despite large numbers of eggs being laid, there was no pronounced peak of first-instars, and very few were extracted from the soil samples. However, the number of larvae extracted increased towards the end of August as a result of eggs laid later in the season.

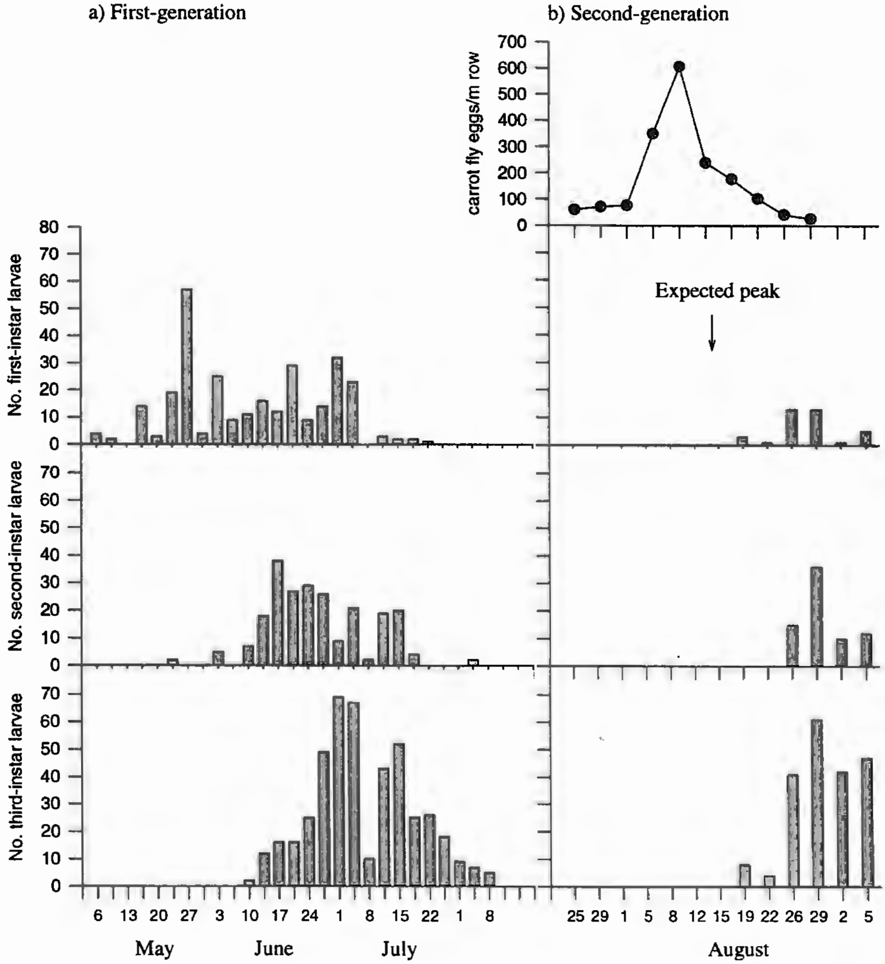

Figure 2. The number of carrot fly larvae recovered from 12 soil cores taken from undamaged carrots during the first and second fly generations in 1997. Egg data are shown for the second generation only.

The carrot plot was irrigated throughout the summer on a regular basis, but maximum air temperatures between 5-22 August were exceptionally high, and averaged 28.6°C. Soil temperatures of over 26°C were recorded on eleven days during the same period.

Soil moisture as a mortality factor

A high proportion (78%) of eggs hatched in most of the soil moistures that were tested (Figure 3). However, at 5% FC there was 100% mortality, and many of the eggs were intact but had collapsed inwards, a sign of desiccation. In addition, when the soil was very wet, 90% of the eggs were killed but this did not affect their visual appearance.

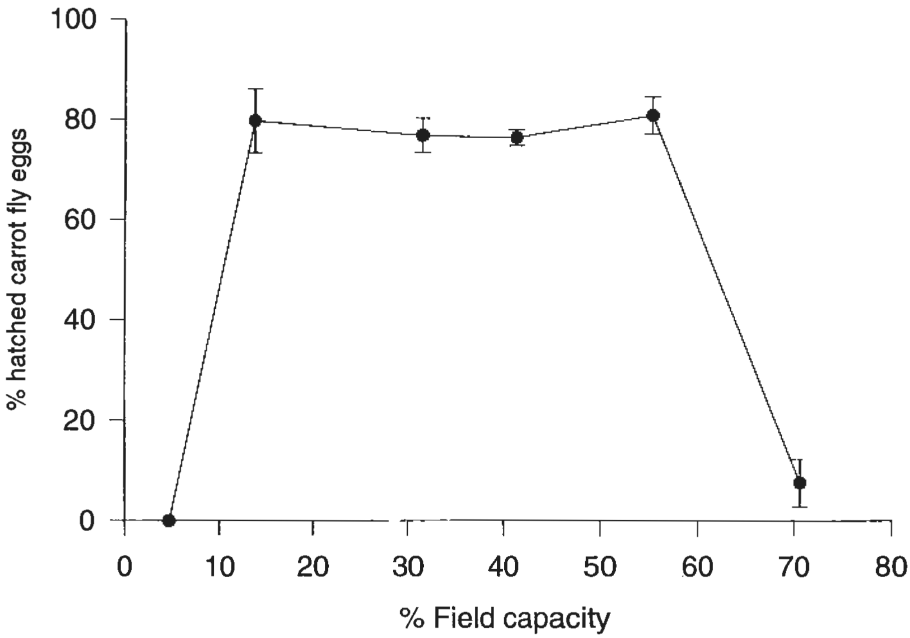

Figure 3. The percentage of carrot fly eggs that hatched at 20°C after exposure to different soil moisture contents. Error bars = standard errors.

The survival of first-instar larvae was reduced markedly by dry conditions (Figure 4). When the compost was wet, almost 60% of the larvae survived to pupation compared to only 5% (88% mortality) in the very dry treatment.

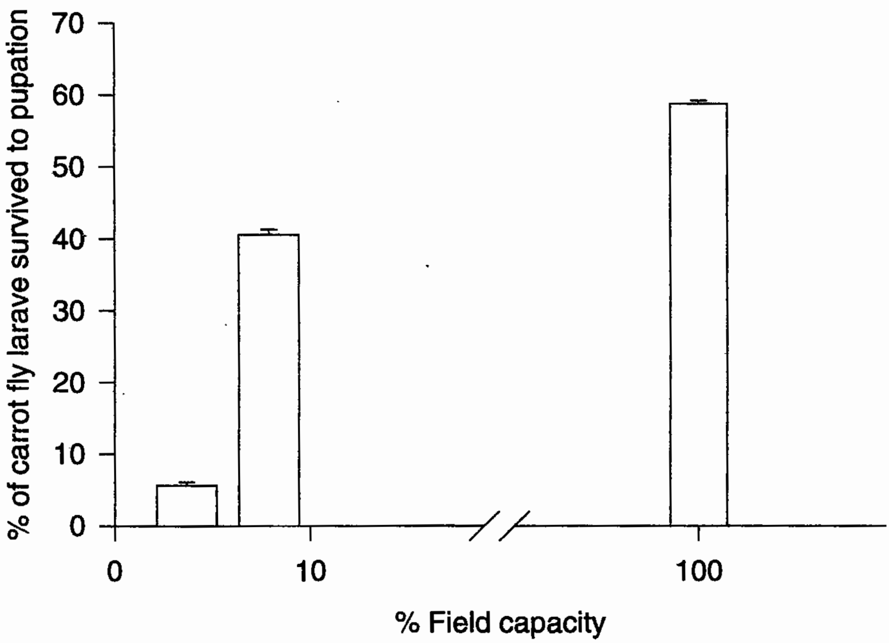

Figure 4. The percentage of first-instar carrot fly larvae that survived to pupation after a 4-day exposure to two dry compost treatments. Error bars = standard errors.

Discussion

Under field conditions, more carrot fly eggs were laid on the undamaged, rather than previously-damaged carrots. This is contrary to published evidence, which suggests that the flies should be attracted more by damaged carrots, due to the presence of the phenolic compound, chlorogenic acid. Cole (1985) showed that the peel from carrots damaged by carrot fly contained about twice as much chlorogenic acid as that from undamaged carrots. Thus the flies were expected to prefer the damaged carrots. Therefore it seems that chlorogenic acid either does not have such a strong influence as thought previously, or that its effect is masked by the many other factors influencing oviposition under field conditions. In addition, carrot flies have been found to be equally attracted to carrot foliage in the yellow-green region of the spectrum (Degen & Städler, 1997), and so should not have been deterred by the foliage being more yellow in the damaged carrots. It therefore seems probable that the flies were attracted equally to both types of carrot, but were then repelled by detecting that some leaves on the damaged plants had begun to senesce. This would explain also why some eggs were laid on the damaged carrots, as not all the leaves were senescing, and a fly landing on a healthy leaf may have been stimulated sufficiently to oviposit.

It has been known for many years that both high temperature and low soil moisture in the UK have an adverse effect on carrot fly populations. During a period of very dry soil conditions, despite a large number of eggs being laid and half of them hatching, negligible damage was found at harvest (Petherbridge *et al.*, 1946). A high mortality of eggs was recorded also at temperatures above 26°C (Overbeck, 1978). Finch & Vincent (1996) recorded a population crash during the first generation in 1995 that resulted from high temperatures. High temperatures also appear to have been responsible for the high first-instar mortality recorded in 1997, as all other conditions for development were favourable. However, the later larvae were able to survive, and this allowed the population to recover towards the end of August by which time the temperature had declined slightly.

Both carrot fly eggs and first-instar larvae were relatively tolerant to dry soil conditions. The eggs were able to hatch at the normal rate (~80%) even at moisture contents as low as 14%FC. There appeared to be a desiccation threshold below 14%FC, as the mortality rate was 100% at 5%FC. It was not possible to compare directly the moisture contents affecting egg and larval survival in this study, as the compost and soil used in the tests had different water retention properties. However, some larvae withstood even the driest compost treatment. Again there appeared to be a threshold, as very high mortality did not occur in the intermediate treatment which was also very dry.

The type of data recorded here could be incorporated into the forecasting model (Finch *et al*, 1996). Currently, developmental day-degrees (Collier & Finch, 1996) are used as the basis for the forecasts (Phelps *et al.*, 1993). By recording detailed environmental conditions and estimating the subsequent egg and larval mortality, the time at which peak damage could be expected could be incorporated into the forecast. The mortality data may also give an indication of the potential size of the forthcoming adult population. Moreover, the mortality data could also be used to estimate the period when visible damage would start to occur on the roots. Thus advice could be given to growers concerning the optimum time to harvest the crop to avoid visible damage on the final produce. However, additional mortality data need to be collected, particularly for the other developmental stages of the carrot fly, before a robust system could be implemented.

Résumé

Programme de lutte contre les populations de mouche de la carotte, effet des basses humidité du sol sur la mortalité des oeufs et des premiers stades larvaires.

Tous les stades du cycle biologique de la mouche de la carotte ont été suivis au champ en 1997. Les mouches préfèrent pondre sur les carottes qui n'ont pas été exposées précédemment à d'autres mouches plutôt que sur des carottes déjà attaquées par des larves. En raison des hautes températures du mois d'août, les larves de la seconde génération ont souffert au début avec un fort taux de mortalité mais ont résistées par la suite. Sous différentes conditions contrôlées, les oeufs de mouche de la carotte sont tuées soit lorsque le sol contenait très peu d'humidité (< 14% de capacité au champ) soit lorsque le sol était très humide. La mortalité des larves de premier stade était aussi élevée lorsque le sol contenait une humidité faible.

Acknowledgement

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Predators and Parasitoids

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Predatory species of the genus *Orius* recorded in fields of vegetable crops in Greece

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Abstract: A survey was done during 1995, 1996 and 1997 to record the species of the genus *Orius* found on vegetable crops and non-cultivated plants in and around vegetable fields. Six species were recorded. These were *Orius niger* (Wolff), *O. laevigatus* Fieber, *O. maderensis* Reuter, *O. minutus* (L.), *O. vicinus* Ribaut and *O. horvathi* Reuter. The most frequently encountered species was *O. niger* followed by *O. laevigatus*. The remaining species were less frequent. In a few cases, more than one species was found on the same plant. *Orius* species appeared earlier in the season on non-cultivated plants than on plants of field vegetable crops.

Key words: Predatory insects, *Orius niger, O. laevigatus,* egg plant

Introduction

Species of the genus *Orius* Wolff are small, dark-brown to black bugs. They feed on thrips, aphids, whiteflies, mites and eggs of various Lepidoptera, but they can also feed on pollen (Tonks, 1953: Southwood & Leston, 1959; Kelton, 1963; Ghauri, 1980; Ferragut & Gonzalez Zamora, 1994). Certain species of *Orius* feed exclusively on pollen (Ferragut & Gonzalez Zamora, 1994). During their development, species of *Orius* pass through the egg and five nymphal stages. Once they have mated, the females lay their eggs in plant tissues. Identification is based mainly on the left genital clasper of the male, as this appears to be a relatively constant character (Wagner, 1952; Stichell, 1962; Herring, 1966).

The aim of this study is to obtain information on the distribution and ecology of the various species of *Orius* that can be found, in and around vegetable fields, in various areas of Greece.

Materials and methods

Samples, mainly from central and southern Greece, were collected during 1995, 1996 and 1997. These samples were collected from plants in vegetable fields and non-cultivated plants in, and around, vegetable fields.

Usually the top part of the plant, including flowers, was collected, as most *Orius* eat some pollen in addition to the insect prey they find on plant leaves. Each sample was placed into a plastic bag before being taken to the laboratory and inspected for *Orius*. The *Orius* species were identified using the keys of Wagner (1952), Stichell (1962), Kelton (1966), Herring (1966) and Ferragut & Gonzalez Zamora (1994).

Results

In total, six different species of *Orius* were found (Table 1). The most common was *Orius niger* (Wolff). This species was found on *Solanum melongena*, *Capsicum annuum*, *Cucumis sativus* and on many non-cultivated plants, and was found from early-May to mid-October (Figure 1). *O. laevigatus* Fieber was found on *C. annuum*, *Lycopersicum esculentum*, *C. sativus*, *C. melo* and on a number of non-cultivated plants.

Table 1. *Orius* species found on vegetable crops and on non-cultivated plants growing in and around vegetable fields (A.U.A. = Agricultural University of Athens).

Orius Species	Plant Species	Area (County)
O. niger	*Solanum melongena*	Orchomenos, Vaghia, Thiva (Boiotia), Killini, Amaliada (Ilia)
	Capsicum annuum	Pelasgia Parorio (Fthiotida), Amaliada, Killini (Ilia), Messologgi (Aitol/nia)
	Cucumis sativus	A.U.A. (Attica), Paramithia (Thesprotia)
	Lycopersicum esculentum	Paramithia (Thesprotia)
	Malva neglecta	Paramithia (Thesprotia)
	Marrubium peregrinum	Messologgi (Aitol/nia)
	Verbascum phlomoides	Pilio (Magnissia)
	Echium plantagineum	Tripoli (Arkadia)
	Ammi huntii	Tanagra (Boiotia), Volos (Magnissia) Philippiada (Preveza)
	Cardaria draba	Tanagra (Boiotia)
	Onopordum illyricum	Nea Kios (Argolida)
	Marrubium vulgare	Nea Kios (Argolida)
	Chenopidium album	A.U.A. (Attica)
	Amaranthus lividus	A.U.A. (Attica)
	Malva sylvestris	Volos (Magnissia)
	Stachys cretica	Volos (Magnissia)
	Silybum marianum	Messologgi (Aitol/nia)
	Carlina corymbosa	Messologgi (Aitol/nia)
	Carduus pycnocephallus	Philippiada (Preveza)
O. laevigatus	*Capsicum annuum*	Messologgi (Aitol/nia), Killini (Ilia)
	Cumumis sativus	Paramithia (Thiesprotia)
	Cumumis melo	Akraifnio (Boiotia), Volos (Magnissia)
	Ammi huntii	Akraifnio (Boiotia), Volos (Magnissia)
	Carduus pycnocephallus	Philippiada (Preveza)
	Helianthus annuus	A.U.A. (Attica)
O.maderensis	*Solanum melongena*	Messologgi (Aitol/nia), Amaliada (Ilia)
	Solanum cornutum	Chalkida (Evia)
	Amaranthus lividus	A.U.A. (Attica)
	Verbascum phlomoides	Messologgi (Aitol/nia)
	Datura stramonium	Philippiada (Preveza)
O.minutus	*Solanum melongena*	Messologgi (Aitol/nia)
	Capsicum annuum	Messologgi (Aitol/nia)
	Lycopersicum esculentum	Paramithia (Thesprotia), Amaliada (Ilia)
O.vicinus	*Solanum melongena*	A.U.A. (Attica)
O.horvathi	Chenopidium album	A.U.A. (Attica)

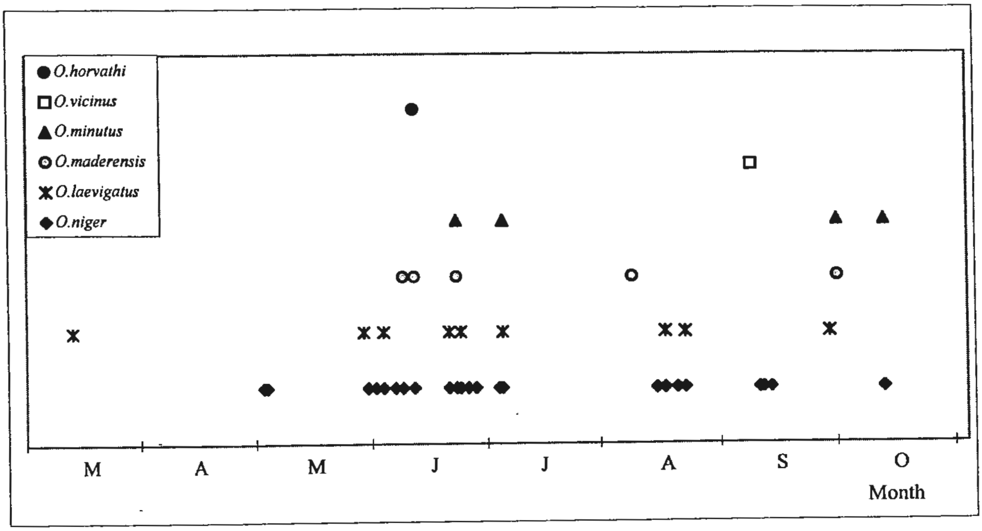

Figure 1. Seasonal appearance of *Orius* species found on plants growing in and around vegetable crops in Greece during 1995, 1996 and 1997.

It was found less common than *O. niger*. Both species occurred together on *C. sativus*, *Cardaria draba*, *Ammi huntii* and *Carduus pycnocephallus*. *O. laevigatus* was found from early-March to the end of September (Figure 1). *O. minutus* (L.) was found on *S. melongena*, *C. annum* and *L. esculentum*. In all cases, it was found with other *Orius* species. For example, it was found with *O. niger* on *C. annum*, with *O. laevigatus* on *L. esculentum* and with *O. maderensis* Reuter on *S. melongena*. Similarly, *O. maderensis* was found on *Solanum cornutum*, *Verbascum phlomoides* and *Datura stramonium*, and occurred with *O. niger* on *Amaranthus lividus*. Two other *Orius* species were recorded, *O. vicinus* Ribaut from *S. melongena* and *O. horvathi* Reuter from *Chenopodium album*.

Discussion

Six *Orius* species were found on plants in field vegetable crops. These were: *O. niger*, *O. laevigatus*, *O. maderensis*, *O. minutus*, *O. vicinus* and *O. horvathi*. Previously, five species of *Orius* (*O. niger*, *O. laevigatus*, *O. majusculus*, *O. minutus* and *O. vicinus*) have been recorded in Britain (Woodroffe, 1971) and six (*O. laevigatus*, *O. albidipennis*, *O. niger*, *O. majusculus*, *O. lindbergi* and *O. pallidicornis*) species in Spain (Ferragut & Gonzalez Zamora, 1994).

Compared to the rest of the *Orius* species, *O. niger* was found on a large number of host plants that included various vegetables and non-cultivated plants. In contrast, *O. vicinus* and *O. horvathi* were each found on only one host plant (Figure 2). From the vegetable crops, egg-plant was the plant on which the largest number of *Orius* species was recorded. The non cultivated plant *A. huntii*, a plant common in Greece, was the one on which more *Orius* (*O. niger* and *O. laevigatus*) were recorded than any other non-cultivated plant. The first *Orius*, a

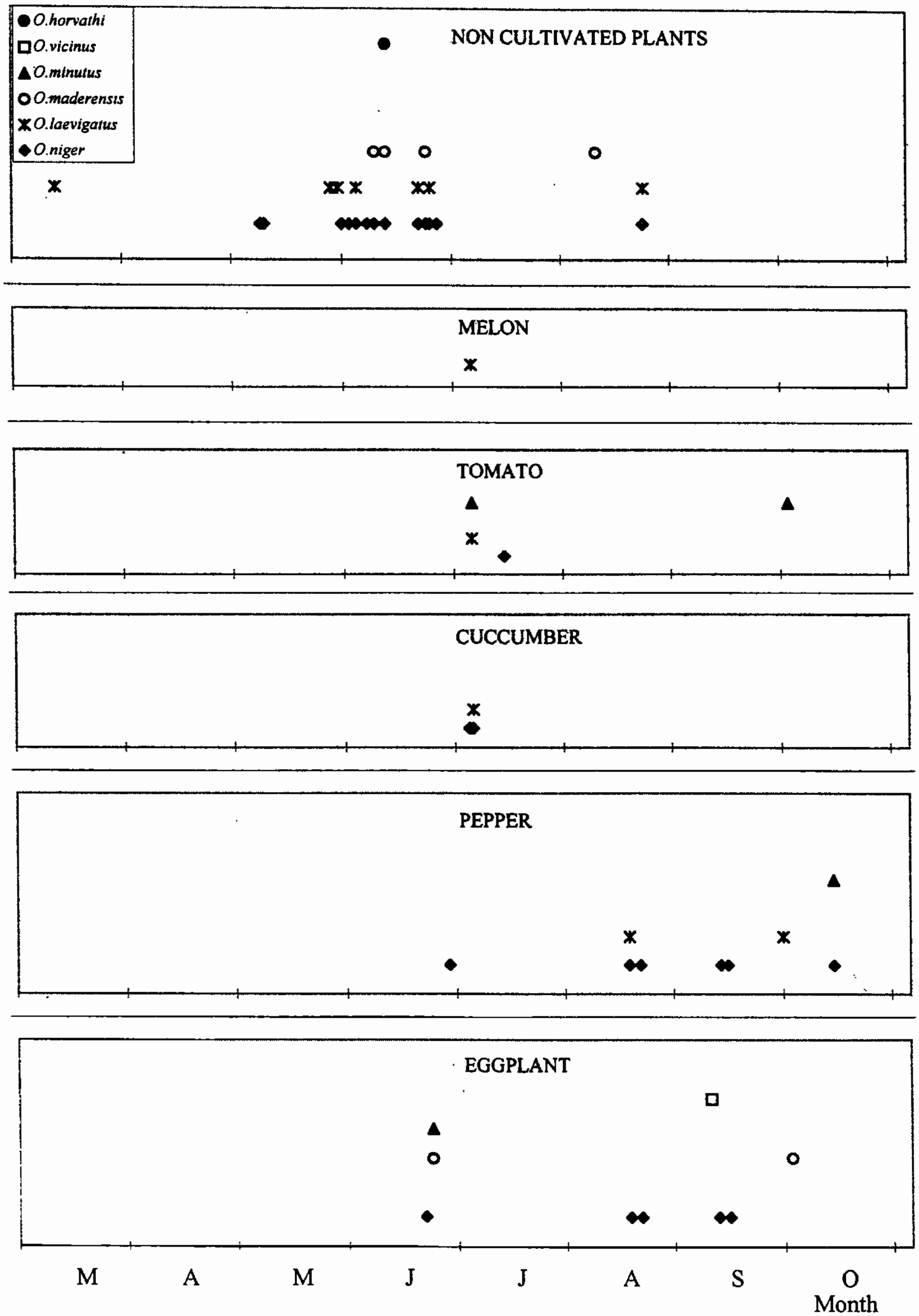

Figure 2. *Orius* species found during the season on various non-cultivated plants and vegetable crops in Greece during 1995, 1996 and 1997.

specimen of *O. laevigatus*, was caught on 13 March 1997 in the flowers of ***Ecballium elaterium***.

Orius spp. appeared earlier in the season on non-cultivated plants than on the plants in the field vegetable crops (Figure 2). This is probably because the *Orius* overwinter on non-cultivated plants, which have a considerable role in the maintenance of *Orius* populations during the winter period.

Résumé

Les espèces prédatrices du genre *Orius* dans les champs de culture légumière en Grèce.

Un suivi a été réalisé au cours des années 1995, 1996 et 1997 pour recenser les espèces du genre *Orius* trouvées sur les cultures légumières et les plantes non cultivées dans et autour des parcelles. Six espèces ont été recensées. Nous avons trouvé *Orius niger* (Wolff), *O. laevigatus* Fieber, *O. maderensis* Reuter, *O. minutus* (L.), *O. vicinus* Ribaut et *O. horvathi* Reuter. L'espèce la plus fréquemment rencontrée est *O. niger* suivi de *O. laevigatus*. Les espèces restantes furent moins fréquentes. Dans quelques cas, plus d'une espèce était trouvée sur la même plante. Les espèces d'*Orius* apparaissent plutôt en saison sur les plantes non cultivées que sur les plantes des parcelles de légumes.

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Variation in the rate of parasitism of *Delia radicum* in the west of France

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Abstract: The rate of parasitism of *Delia radicum* has been studied during the last three years in five localities in the West of France. In all localities, the parasitoids were caught in two types of trap, yellow water traps and pitfall traps. The traps were placed in crops of turnips that had been sown sequentially on five different dates. Two months later, fly pupae were picked from the soil and taken into the laboratory. In the yellow water trap, *Aleochara bipustulata* adults were caught first. The first *A. bilineata* adults were caught about fifteen days later. Catches in the pitfall traps for both species started in the beginning of May. The first sowing of turnips suffered considerable damage each year, whereas the last sowing was protected by the natural populations of *A. bilineata* and *A. bipustulata*. The proportion of parasitoids varied with season, with locality and from year to year.

Key words: *Delia radicum,* parasitoids, *Aleochara bilineata, A. bipustulata, Trybliographa rapae*

Introduction

During the last meeting at Guitté, Brunel & Fournet (1996) recorded the parasitoids associated with the cabbage root fly (*Delia radicum* L. Diptera: Anthomyiidae), the major pest of cruciferous crops in Brittany. Although the first experiment was done on sequential sowings of turnips and it was restricted to just one site. In contrast the 1996 and 1997 experiments were done on all five experimental stations of vegetable crops in the west of France, to determine the effect of predators and parasitoids in crops not treated with insecticide. *Trybliographa rapae* West., *Aleochara bilineata* Gyll. and *A. bipustulata* L. are the main parasitoids in the west of France. To use them in biological control, it is necessary to know their natural abundance throughout the year so that the numbers to be released subsequently can be calculated accurately to minimize the cost per unit area of crop of releasing beetles.

Materials and methods

The same trial was done for the three years (1995 to 1997). In five localities situated at Saint Pol (29), Pleumeur Gautier (22), La Rimbaudais (35), Barfleur (50) and Lorgies (59), plots of rape were sown sequentially from April to July. To estimate the numbers of fly adults, a water trap were placed in each plot. The numbers of rove beetles and carabid beetles were recorded using pitfall traps. The insect populations were estimated by sampling from the traps on a regular basis. Two months after each sowing date, pupae of *D. radicum* were collected from thirty samples (30 x 20 x 15 cm) of soil. The pupae collected were placed at 20°C, 70% RH and 16:8 L/D in the laboratory until the flies and parasitoids had emerged. The rate of parasitism was calculated for each sowing date and locality.

Results

The results are shown in Tables 1, 2, and 3.

Table 1. Numbers of *D. radicum* (D. r .), *A. bilineata* (Bilin), *A. bipustulata* (Bipust), *T. rapae* (T. r.) and *Phygadeuon* sp. (Phy) that emerged in 1997 from fly pupae collected from different localities in France.

Localities	Sowing		Total no. pupae (nP)	D. r.	Bilin	Bipust	T. r.	Phy	No. emerged
Rimbaudais	1		471	135	76	4	13	0	228
		% emerg.		59	33	2	6	0	
		% nP		29	16	1	3	0	49
	2		325	236	10	11	11	2	270
		% emerg.		87	4	4	4	1	
		% nP		73	3.	3	3	1	83
	3		59	18	7	1	2	0	28
		% emerg.		64	25	4	7	0	
		% nP		31	12	2	3	0	48
	4		0						
Pleumeur	1		217	30	41	0	6	0	77
		% emerg.		39	53	0	8	0	
		% nP		14	19	0	3	0	35
	2		494	129	53	7	55	1	245
		% emerg.		53	22	3	22	0	
		% nP		26	11	1	11	0	49
	3		718	39	165	13	17	7	241
		% emerg.		16	68	5	7	3	
		% nP		5	23	2	2	1	33
	4		144	20	37	4	1	0	62
		% emerg.		32	60	6	2	0	
		% nP		14	23	3	1	0	43
	5		343	212	30	0	44	0	286
		% emerg.		74	11	0	15	0	
		% nP		62	9	0	13	0	84

In the data collected from the sequentially-sown plots, the numbers of *D. radicum* eggs collected correlated well with adult abundance. There was a trend for insect numbers to decrease from the first to the fifth date of sowing. In the late sowings, the mean value was about 5 eggs per plant. Catches of the two species of *Aleochara* in pitfall trap began in May and increased as the year progressed.

Attack was high on the first sowing and negligible on the last. In addition, the numbers of pupae collected declined from sowing 1 to sowing 5 (Table 3). The numbers of pupae per linear metre ranged from 186 at Barfleur to 5 at Lorgies.

Table 1. Continued.

Localities	Sowing		Total no. pupae (nP)	D. r.	Bilin + Bipust	T. r.	Phy	No. emerged
Barfleur	1		1675	724	146	91	0	961
		% emerg.		75	15	10	0	
		% nP		43	9	5	0	57
	2		596	128	63	6	0	197
		% emerg.		65	32	3	0	
		% nP		21	11	1	0	33
	3		928	54	172	13	0	239
		% emerg.		23	72	5	0	
		% nP		6	19	1	0	26
	4		484	50	13	3	0	66
		% emerg.		76	20	4	0	
		% nP		10	3	1	0	14

Localities	Sowing		Total no. pupae (nP)	D. r.	Bilin	Bipust	T. r.	Phy	No. emerged
Saint Pol	1		852	45	28	0	19	5	97
		% emerg.		46	29	0	20	5	
		% nP		5	3	0	2	1	11
	2		1064	296	32	20	20	0	368
		% emerg.		80	9	5	5	0	
		% nP		28	3	2	2	0	35
	3		1345	12	28	23	3	0	66
		% emerg.		18	42	35	5	0	
		% nP		1	2	2	0	0	5
	4		527	0	7	3	2	0	12
		% emerg.		0	58	25	17	0	
		% nP		0	1	1	0	0	2
Lorgies	1		43	2	12	0	2	3	19
		% emerg.		11	63	0	10	16	
		% nP		5	28	0	5	7	45
	2		48	2	21	0	4	9	36
		% emerg.		6	58	0	11	25	
		% nP		4	44	0	8	19	75
	3		47	6	10	0		3	19
		% emerg.		31	53	0	0	16	
		% nP		13	21	0	0	6	40
	4		33	0	0	0	0	0	0

At all experimental stations, pupal mortality (no emergence) was high and ranged between 17% to 50% (Table 1). The rate of parasitism was specific for each station. We could not discern any north/south or east/west trend in the data from the different localities.

T. rapae was present at all stations at the time of the first sowing. It was found also in the second sowing at Pleumeur and in the third sowing at Saint Pol. Other Hymenoptera were

Table 2. Percentage of cabbage root fly pupae parasitized by *A. bilineata* and *A. bipustulata* in different sowings of rape in 1995, 1996 and 1997 at La Rimbaudais (35)

	A. *bilineata*			A. *bipustulata*		
Sowing	1995	1996	1997	1995	1996	1997
S1	0	11	33	11	22	2
S2	21	65	37	19	11	4
S3	36	14	25	22	24	4
S4	48	25	0	43	8	0
S5	55	0	0	43	0	0

Table 3. Number of pupae of *D. radicum* collected from 30 samples from each sowing in different localities in 1997 (S= Saint Pol, P= Pleumeur Gautier, R= La Rimbaudais, B= Barfleur and L= Lorgies)

	Number of pupae				
Sowing	S	P	R	B	L
S1	852	217	471	1675	43
S2	1064	494	325	596	48
S3	1345	718	59	928	47
S4	527	144	0	484	33
S5	0	343	0	0	0
Total	3788	1916	855	3683	171

found only at Saint Pol (*Phygadeuon* sp.) and at Lorgies (*Phygadeuon* sp. and *Dacnusa* sp.). Identification of these parasitoids would enlarge the known number of parasitoids of *D. radicum*. At other experimental stations, the percentage of *T. rapae* decreased during in the year.

The two species of *Aleochara, A. bilineata* and *A. bipustulata*, were found at the time of the first sowing and the rate of parasitism increased throughout the year. The maximum rates of parasitism were 77% at Saint Pol, 74% at Pleumeur and 72% at Barfleur. The variability of parasitism between years is shown in Table 2 for La Rimbaudais. The most regular increase in parasitism occurred in 1995. The decrease observed in 1996 and 1997 was the result of the large numbers of *Aleochara* in the plots, as the same localities were used in all three years.

Attack by *D. radicum* were very important in the spring. We recorded an increase of the action of parasitoids throughout the year in the crops grown without insecticide. *Aleochara* occurred from the beginning of May until the end of summer. To reduce the overall *D. radicum* population, *Aleochara* should be released as soon as flies are caught.

The ability of *Aleochara* to penetrate pupae previously parasitized by *T. rapae* or other species (Reader & Jones, 1990; Royer *et al.*, 1999) ensures that insects do not emerge from many pupae attacked by more than one parasitoid.

At all experimental stations, the differences in numbers of the two species of *Aleochara* were recorded. The competition between, or additive effect of, the two species needs to be confirmed and explained. Future research will have to be done to ensure that the surroundings are suitable for *Aleochara* in the spring, and that *Aleochara* are released at the start of crop production.

Résumé

Variation des taux de parasitisme de *Delia radicum* L. (Diptera : Anthomyiidae) en France

La mouche du chou est le ravageur le plus important sur les crucifères légumes dans toute la zone holarctique. Une étude conduite dans l'Ouest de la France a permis de mettre en évidence la présence naturelle de nombreux auxiliaires dont *Trybliographa rapae* Westw., *Aleochara bilineata* Gyll. et *A. bipustulata* L. Les résultats obtenus sur les taux de parasitisme dans des semis échelonnés de navets dans cinq stations d'expérimentation légumières, de 1995 à 1997, sont présentés et discutés en fonction des situations géographiques. La pression parasitaire augmente au cours des semis successifs pour atteindre 100% en fin de saison. *A. bipustulata* plus abondant se partage la ressource avec *A. bilineata*. *T. rapae* est surtout présent en début de saison. Les conséquences sur la lutte biologique en cultures légumières de plein champ sont discutées.

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Is the parasitoid staphylinid beetle *Aleochara bilineata* an effective predator of the egg stage of its natural host, the cabbage root fly?

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Abstract: Two small laboratory experiments were done to assess whether the staphylinid beetle *Aleochara bilineata* could be an effective predator of the eggs of its natural host, the cabbage root fly. Results from the first experiment showed that each beetle was capable of destroying about 12 fly eggs/day. However, the beetles did not find eggs placed in the soil, but only those on the soil surface. As the results from the second experiment indicated that no more than 15% of the eggs were found normally on the soil surface, egg predation by *A. bilineata* is not likely to contribute greatly to the overall levels of cabbage root fly control.

Key words: *Delia radicum, Aleochara bilineata,* egg predation

Introduction

During the last 75 years, many authors (see Tomlin *et al.*, 1992) have suggested that it might be possible to control field populations of the cabbage root fly (*Delia radicum* L.) by releasing the parasitoid staphylinid beetle *Aleochara bilineata.* However, no-one has yet used this beetle successfully in the field (Finch, 1996a).

Most researchers (Wadsworth, 1915; Esbjerg & Bromand, 1977; Bromand, 1980; Hertveldt *et al.*, 1984; Tomlin *et al.*, 1992) believe that apart from its benefits as a parasitoid, this staphylinid beetle could also be an effective predator of the eggs and early-larval visitors of the cabbage root fly. It has been suggested, therefore, that *A. bilineata* should be released inundatively at the time the pest fly starts to oviposit (Tomlin *et al.*, 1992), as most early-season brassica crops need to be protected more or less as soon as they are planted (Finch, 1996a). Before considerable time is spent in mass-rearing this beetle, it would seem prudent to test the underlying hypothesis that the beetles will destroy the eggs and the early-larval instars of the cabbage root fly if introduced at, or shortly after, the start of the "fly" infestation.

This paper describes two small experiments to test whether *A.bilineata* adults are capable of destroying appreciable numbers of eggs of the cabbage root fly.

Materials and methods

Predation of cabbage root fly eggs presented above and below the soil surface

Sixteen cabbage plants, at the third true-leaf stage, were transplanted into 15 cm pots. The soil was compacted slightly and then covered with a thin layer (approximately 4 mm deep) of sieved (2 mm mesh) field soil to provide a more natural substrate.

One hundred cabbage root fly eggs were counted onto each of 16 black filter papers and then 100 eggs were washed carefully around the base of each cabbage plant. The eggs on eight of the sixteen plants were covered with a thin sprinkling of field soil until no eggs could be seen. Plastic collars were placed over the test plants and were pushed into the soil to a depth of about 2 cm to enclose both the plants and fly eggs. Four *Aleochara* were introduced inside the collars alongside each of four plants in which the fly eggs were either exposed or covered. The open areas between the tops of the collars and the plants were covered with Parafilm^{R} to prevent the beetles from escaping. The remaining eight plants were used as "controls" to assess how many fly eggs could be recovered from the exposed and covered eggs in the absence of predation by beetles. All of the test plants were kept in a constant environment room, maintained at 18±2°C during the light (L) and dark (D) periods. The room was illuminated at a L16:D8 photoperiod. After 24 hours, the numbers and condition of the eggs recovered by flotation were recorded. The experiment was repeated on five occasions. Hence, the results for each treatment are based on of 20 values.

Percentage of cabbage root fly eggs found above and below the soil surface

Cabbage plants at the third true-leaf stage, were transplanted into 15 cm diameter pots. The soil was compacted slightly and then covered with a 1cm-deep layer of unsieved soil. These test plants were placed into the cages of the cabbage root flies reared continuously (Finch & Coaker, 1969) in the Insect Rearing Unit at HRI Wellesbourne. Flies were allowed to lay for periods of 1, 2, 4 and 6 hours. At the end of each exposure period, the cabbage plants were removed from the cages and the plant stems were cut carefully, without disturbing the soil, about 1 cm above soil level. The surface of the soil was then inspected under a binocular microscope and the white fly eggs, which can be seen clearly on the brown soil, were picked off carefully with a fine moistened paint- brush. Once all of the eggs had been removed from the soil surface, the top 1cm of loose soil was washed from the pot into a beaker of water. The floating eggs were then picked off and counted, to record the numbers of eggs below the soil surface. The four different exposure times (treatments) were each replicated 15 times.

Results

Predation of cabbage root fly eggs presented above and below the soil surface

As a result of the sampling technique, approximately 94-95±1% of the eggs were recovered from the pots in which there were no beetles (Table 1). Similar numbers (93±1%) were recovered from the pots with beetles when the eggs were covered with soil. Predation occurred only when the eggs were exposed on the soil surface. The four beetles released around each plant killed about half of the eggs, or about 12 eggs/beetle, during each 24 hour period. The choria of many (34±5) of the eggs attacked by the beetles were not destroyed completely.

Table 1. The numbers of cabbage root fly eggs recovered from exposed and covered cabbage root fly eggs in the presence and absence of the staphylinid beetle *Aleochara bilineata.*

Position of eggs	No of *Aleochara* /plant	Mean number of fly eggs recovered (100 inoculated)	
		Intact eggs	Damaged eggs
Exposed	0	95±1	0
Exposed	4	49±7	34±5
Covered	0	94±1	0
Covered	4	93±1	0

Table 2. The mean numbers of cabbage root fly eggs found on and below the soil surface when potted brassica plants were placed for 1 – 6 hours in cages containing laboratory-reared cabbage root flies.

Period (h)	Mean numbers of eggs recovered		Percentage of eggs found on soil surface
	a) per plant	b) on soil surface	
1	1	0	0
3	46	3	5
4	183	11	6
6	88	13	15

Percentage of cabbage root fly eggs found above and below the soil surface
It appeared that as the time the plants were left in the fly cages was extended, the more eggs were found on the soil surface (Table 2). However, even when large numbers of eggs were recovered/plant, only between 7% and 15% of them were found on the soil surface (Table 2).

Discussion

In an earlier study, Finch & Elliott (1994) showed that although a wide range of carabid ground beetles (Finch, 1996) were capable of eating cabbage root fly eggs, the beetles managed to eat only the eggs exposed on the soil surface. The same appears to be true for the ground-living staphylinid beetle *Aleochara bilineata*, as although this beetle spends most of its time in the soil, it failed to find any of the cabbage root fly eggs covered by soil. For the progeny of this parasitoid beetle to survive, the adults have to find the immature stages of the cabbage root fly. As the present results indicate that the beetles have no special mechanism for finding the eggs of their host fly, they presumably must receive the appropriate cues from the characteristic chemicals associated with plant damage and the waste products produced by the feeding larvae. Other experiments have shown that the beetles are not attracted to uninfested brassica plants (Finch – unpublished data).

The second experiment showed clearly that the female flies push their eggs into the soil and that, as a consequence, relatively few eggs remain exposed to predators on the soil surface. Under field conditions, it is unusual to recover more than 35 cabbage root fly eggs/plant/day even at the time of oviposition. (Finch *et al.*, 1975). Therefore, even at such times it seems unlikely that more than 3-4 egg plants (10% - Table 2) will be exposed to predatory beetles. Hence the earlier assumption, that *Aleochara* should be capable of destroying large numbers of the eggs of the cabbage root fly, appears to be no longer valid. The value of inundatively releasing this staphylinid beetle as a predator will now depend largely upon whether this beetle can destroy sufficient larvae of the fly to reduce the damage on the roots of crop plants to acceptable levels.

Résumé

Est-ce que le staphylin *Aleochara bilineata* est un prédateur efficace des oeufs de son hôte naturel, la mouche du chou ?

Deux petites expériences de laboratoire furent faites pour estimer si le staphylin *Aleochara bilineata* pouvait être un prédateur efficace des oeufs de son hôte naturel, la mouche du chou. Les résultats de la première expérience montrent que le staphylin est capable de détruire environ 12 oeufs de mouche par jour. Cependant les staphylins n'ont pas trouvé les oeufs placés dans le sol, mais seulement ceux placés à la surface du sol. Les résultats de la seconde expérience indiquent qu'il n'y a pas plus de 15% des oeufs qui ont été trouvés à la surface du sol ; la prédation par *A. bilineata* ne peut vraisemblablement pas contribuer énormément à lutter contre la totalité des niveaux de population de mouche du chou.

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A hypothesis to explain the competition between two staphylinid parasitoids of *Delia radicum*

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Abstract: The two rove beetles *Aleochara bilineata* Gyll. and A. *bipustulata* L. both develop within the pupal stage of the cabbage root fly, *Delia radicum* L., and hence exploit the same resource. The co-existence of the two beetles is made possible by "resource partitioning" at the larval stage. This situation is only possible because the larvae of both species possess specific advantages which allow them to reduce interspecific competition. The aim of this study is to verify certain hypotheses concerning resource partitioning and in particular to describe the differences in microspecialization that occur between the larvae of the two species.

Key words: *Delia radicum, Aleochara bilineata, A. bipustulata*

Introduction

In theory, co-existing species may avoid competition by feeding on different resources. Nevertheless, in nature, there are several examples of species that co-exist through resource partitioning, which is a violation of the Gause principle.

However, exploiting the same resource generates strong interspecific competition. According to the Gause principle, the outcome of such a situation should be the exclusion of one of the competitors; as Hardin (1960) states that "Two species with similar ecology that live side by side cannot exploit the same resource". The Gause principle applies only when competitors have to exploit the same resource in an environment (Gause, 1935; Park, 1962; in Barbault, 1992). In this case, the overlap of the ecological niche of each species is at a maximum. In nature, interspecific competition causes a diminution in the level of overlap, which is favourable through resource partitioning, to co-existence. Resource partitioning can result from different mechanisms such as: spatial and temporal variations in resource exploitation (Ziv *et al.*, 1993), and morphological differences resulting from selection (Barbault, 1992; Dajoz, 1972). All of these are based on the fundamental principle that – Every competitor must possess an advantage that the other does not have, to exploit the resource (Godfray, 1994). It is on this last principle that we have based our hypothesis on the system concerning the two beetle parasitoids, *Aleochara bilineata* and *A. bipustulata*, and their host the cabbage root fly, *Delia radicum*.

Experimental section

1: **A. bipustulata** *and* **A. bilineata***: Two sympatric species that parasitize cabbage root fly,* **Delia radicum,** *pupae.*

The cabbage root fly, *D. radicum*, is the major pest insect of cruciferous crops in Brittany. In 1981, Lahmar studied the biology of *D. radicum* in Brittany and made a list of its natural enemies. Among the most important of its parasitoids were *Trybliographa rapae* West., *A. bilineata* and *A. bipustulata*. The two staphylinid beetles co-existed in the same fields and used the same resources: eggs of the fly for the adults beetle and pupa for the first-instar larvae (Brunel & Fournet, 1996).

In 1995, at La Rimbaudais Experimental Farm (Brittany, France) observations were made in a large area of cruciferous crops. Our observations indicated that:

- At the end of summer, 100% of the overwintering pupa were parasitized. The resource then looked to be limiting.
- Although fewer: *A. bilineata* were caught, its levels of parasitism were similar to those of *A. bipustulata.*

These results indicate that the two species co-exist despite having similar ecological niches and development cycles. According to Godfray (1994), this situation is possible only if each species possesses a decisive advantage for exploiting the resource.

We propose that the resource partitioning could be due to:

1 The presence of larval microspecialisation
2 Differences in the laying potential of the two beetles
3 Differences in the size of the host pupae used by the two beetles.

The second possibility is still to be studied.

2: Laboratory experiments

Two aspects of the first hypothesis were studied:

a) the beetle larva's ability to penetrate fly pupa
b) the beetle larva's capacity to discriminate

a: Beetle larva's ability to penetrate fly pupae

The mandibles of the first instar larvae were studied under the microscope. No differences could be found between the two species. Therefore, the larvae of both species appear to have the same potential to penetrate fly pupae (Fournet, 1996).

The speed of penetration by the beetle larvae was also studied. The results were the same for both *A. bilineata* and *A. bipustulata,* with 80% penetration occurring after 48 hours. This supports the mandible observations (Fournet, 1996; Royer *et al*, 1998).

In a final experiment, competition between the larvae of the two species was studied. One larvae of each beetle species was placed onto each pupa of *D. radicum.* The percentage emergence did not differ between the two species: 12% of the beetles that emerged eventually were *A. bilineata* and 10% were *A. bipustulata,* (Fournet, 1996). In this experiment beetle mortality was very high (77%), due mainly to multiparasitism in many of the pupae. Fuldner (1960) showed that two larvae competing for one pupa fight, either outside or inside the pupa, until one is killed.

b: The beetle larva's capacity to discriminate

Discrimination by the first-instar larvae was studied in "no-choice" and "choice" experiments.

In the "no-choice" experiments, tests were done on the capacity of larvae to penetrate pupae parasitized by a conspecific or another species. The results were not the same for the *A. bilineata* and the *A. bipustulata* larvae (Royer *et al*, 1998). Few *A. bipustulata* larvae entered pupae already parasitized by *A. bilineata* or by a conspecific. In contrast, *A. bilineata* larvae entered pupae parasitized by *A. bipustulata* more frequently than they entered pupae parasitized by conspecifics (Fournet, 1996).

However, multiparasitism by *A. bilineata* larvae does not appear to be adaptive, as only 8% of the *A. bilineata* larvae survived to the adult stage. Nevertheless, it is adaptive for the few larvae that manage to complete development.

In choice experiments, the two species of *Aleochara* studied avoided multiparasitism when allowed to choose between unparasitised and parasitized pupae (Fournet, 1996; Royer *et al*, 1997).

3: Parasitism of different sized pupae

According to Ahlström-Olsson (1992) & Jonasson (1994), *A. bipustulata* and *A. bilineata* do not parasitise the same size of pupae. *A. bipustulata* prefer small pupa whereas *A. bilineata* prefers large pupae.

In reality, each species can probably parasitize all sizes of pupae. However, there may be a slight preference for small or large pupa respectively for *A. bipustulata* and *A. bilineata* when they are alone, or when the resource is not limiting. When the resource is limiting, however, small pupa and large pupa can become ecological refuges. In such cases, the level of interspecific competition is lower and so, favourable to co-existence. This hypothesis is now being studied.

Discussion

A bilineata and *A. bipustulata* larvae appear to have a similar capacity to penetrate pupae of *D. radicum*. In competition, neither species manages to dominate the fights that occur inside or outside of the fly pupae. The significance of mortality in this situation, lead us to study multiparasitism. This study shows that multiparasitism allows the two species to discriminate between hosts. Generally the larvae distinguish parasitised from unparasitised pupae. In "no-choice" experiments, *A. bilineata* larvae preferred to parasitize pupae occupied by the other species than ones occupied by a conspecific. This higher power of discrimination is an important adaptive advantage (Bakker *et al*, 1985).

At present, we cannot conclude which of the two *Aleochara* species is likely to be more suitable as a biological control agent. Further research is needed to clarify what is happening under field conditions and to determine whether only one, or both, of the *Aleochara* species will need to be used at any given time.

Résumé

Compétition et coexistence entre deux staphilins parasitoïdes de la mouche du chou *Delia radicum*

Face aux problèmes posés par la mouche du chou *Delia radicum*, différentes pistes de lutte biologique sont envisageables, en particulier, en utilisant les capacités prédatrices et parasitaires de deux coléoptères, *Aleochara bilineata* Gyll. et *A. bipustulata* L. Ces deux coléoptères exploitent la même ressource aussi bien au stade adulte que larvarie pour se mourrir et se multiplier. Leur coexistence sur une même parcelle a éte démontrée et est rendue possible par un phénomène de partage de la ressource au niveau larvaire. Ce type de situation n'est possible que lorsque chacune des deux espèces concurrentes possède un avantage décisif lui permettant de diminuer la compétition interspécifique et d'exploiter la ressource. Le but de cette étude est de vérifier certaines hypothèses permettant d'expliquer ce partage de la ressource en s'intéressant plus spécifiquement à l'existence de microspécialisation larvaires.

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The effect of undersowing brassica crops with clover on host finding by *Trybliographa rapae* and *Aleochara bilineata*, two parasitoids of the cabbage root fly, *Delia radicum*

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Abstract: A field-cage study was done to compare parasitism of the cabbage root fly, *Delia radicum* (L.), by the wasp *Trybliographa rapae* Westwood (Hymenoptera: Cynipidae) and the beetle *Aleochara bilineata* Gyllenhal (Coleoptera: Staphylinidae), around cauliflower (*Brassica oleracea* var. *botrytis* L.) plants grown in bare soil and around cauliflower plants undersown with clover (*Trifolium subterraneum* L.). Prior to the release of the parasitoids, the individual crop plants were inoculated with *D. radicum* eggs to ensure that initial pest numbers were similar irrespective of background. The number of *D. radicum* pupae parasitized by either *T. rapae* or *A. bilineata* was not affected significantly by the presence of clover. Where parasitoids were released, the level of parasitism by *T. rapae* was consistently higher than that by *A. bilineata*. However, the effectiveness of *T. rapae* as a parasitoid was reduced in the presence of *A. bilineata*. The results suggest that the two parasitoids, unlike the cabbage root fly, use chemical- rather than visual-cues to locate their host. The implications of this host-finding behaviour for future IPM strategies are discussed.

Key words: *Delia radicum, Trybliographa rapae, Aleochara bilineata,* undersowing, *Trifolium subterraneum*

Introduction

Numerous studies have shown that infestations of cabbage root fly (*Delia radicum* L.) can be reduced in size by increasing crop diversity through intercropping or undersowing (O'Donnell & Coaker, 1975; Ryan *et al.*, 1980; Tukahirwa & Coaker, 1982; Theunissen *et al.*, 1992; McKinlay *et al.*, 1996). By undersowing cabbages with slow-growing clover, Theunissen *et al.* (1992) demonstrated the possibility of producing a marketable crop without the use of pesticides. However, to provide an effective barrier to pest infestation the growth of this ground cover must be managed precisely. To reduce oviposition by cabbage root fly, O'Donnell & Coaker (1975) showed that the clover must cover at least 60% of the bare ground within the brassica crop and, more recently, Finch & Kienegger (1997) showed that it must also conceal at least 50% of the vertical profile of the crop plants. These precise management requirements, necessary to maintain an effective clover cover, can be difficult to meet under field conditions. The reliability of undersowing as a method of pest control could be improved by enhancing the control exerted by natural enemies of the cabbage root fly. However, there is concern that the same mechanism that causes the cover crop to impede host plant finding by pests also impedes host insect finding by their respective natural enemies.

This paper describes a preliminary study to determine whether undersowing brassica plants with clover (*Trifolium subterraneum* L.) reduced parasitism of the cabbage root fly by the wasp *Trybliographa rapae* Westwood (Hymenoptera: Cynipidae) and the beetle *Aleochara bilineata* Gyllenhal (Coleoptera: Staphylinidae). The results of a similar study, conducted recently by Langer (1996), were inconclusive about the effect of clover on parasitism by the wasp, but indicated that the risk of parasitism of fly pupae by the beetle was reduced by the presence of the clover. Two possible reasons for the inconsistency of Langer's (1996) results are that (1) the density of fly hosts was not kept constant (she examined naturally-occurring levels of parasitism in fly pupae surrounding cabbages infested by naturally-occurring levels of the pest) and (2) the clover in her field plots covered less than 60% of the ground area and was intercropped between the rows of cabbages in such a way that the cabbages grew in strips of bare soil at least 25 cm wide. By inoculating brassica plants with a known number of the fly pest and then transplanting these plants into a full cover of clover, or bare soil, the present study was designed to eliminate these sources of variation and thus clarify the interactions between clover cover and parasitism of fly pupae by wasps and beetles.

Materials and methods

Insects

All insects used in the experiment were obtained from cultures maintained in the Insect Rearing Unit at HRI Wellesbourne.

Cabbage root fly eggs were obtained from the continuous culture maintained using the method developed by Finch & Coaker (1969). The fly eggs used to inoculate the experimental plants were less than 24 hours old.

The adult wasps used in the experiment were obtained from field-collected fly pupae. Once they had emerged from the fly pupae, the wasps were kept in a large ventilated Perspex® cage (50 cm^3) until they were required for experimental purposes. These wasps were maintained under the same environmental conditions and provided with the same diet used for the adult flies (Finch & Coaker, 1969).

Adult beetles were obtained from a continuous culture. The culture was started, and supplemented regularly, with adults that had emerged from field-collected fly pupae. Groups of *c.* 100 beetles were placed in clear polystyrene boxes (17 cm x 11.5 cm x 6 cm high) half-filled with damp silver sand. Adult beetles were supplied twice weekly with five blowfly maggots per box as food. For rearing purposes, groups of *c.* 20 beetles were moved into smaller boxes (8 cm x 14 cm x 5 cm high) similarly-filled with damp sand. No specific sex ratio was maintained; the beetles were allowed simply to mate and oviposit. One hundred fly pupae, obtained from the continuous culture described above, were placed into each rearing box to provide potential hosts for hatched beetle larvae. The resulting parasitized pupae were stored in damp vermiculite until the adult beetles emerged. All beetle cultures were maintained at 12 ± 2 °C and a L8:D16 photoperiod. Higher temperatures increased the incidence of cannibalism.

Mixed ages of parasitoid adults were released into field cages (see below) at the rate of three adults per brassica plant.

Plants

Cauliflower (*Brassica oleracea* var. *botrytis* L., cv. White Rock) was used as the test brassica plant for the experiment. The brassica plants were grown from seed in Hassy 308 plastic modular trays (Erin Planter Systems Ltd., Baldock, Herts., UK) in a glasshouse. At the three-leaf growth stage, the plants were removed from the modules and planted into 10 cm pots containing John Innes loam-based compost.

The cauliflower plants were left for seven days to establish and were then inoculated with 40 fly eggs; washed onto the soil surface around the base of the stem of each plant. The inoculated plants were left for a further four days, to allow the eggs to hatch, before being transplanted into the field plot.

The field plot used in the experiment consisted of a 30 m x 3.6 m strip of subterranean clover (*Trifolium subterraneum* L., cv. Claire), drilled during early April, surrounded by a 4 m wide area of bare soil. When the experiment was started, in early July, the clover was *c.* 10 cm high.

A total of 288 cauliflower plants (240 inoculated and 48 controls) were transplanted into the field plot and covered with cages, according to the experimental design below, and left for three days before the release of the 'week 1' parasitoids (see below). 'Week 2' parasitoids were released seven days later.

The experimental plot was irrigated daily throughout the course of the experiment.

Field cages and experimental design

The field cages were made from 0.5 mm mesh polyester netting, supported internally by metal arches (1 cm gauge steel wire, 80 cm x 45 cm high). Two cage sizes were used: 160 cm x 60 cm x 45 cm high and 80 cm x 60 cm x 45 cm high. The skirting of each cage wall was covered with soil to make the cages insect-proof.

The effects of three backgrounds on the levels of parasitism of the fly were examined: bare soil, clover, and a 50:50 mixture of bare soil and clover. Small field cages were used to enclose areas of either bare soil or clover while the larger cages enclosed the mixed backgrounds. The cages were placed 60 cm apart along the two long edges of the clover strip. Four brassica plants were transplanted 30 cm apart directly into each clover or bare soil area within the cages (Figure 1). A 10 cm strip of clover was left at the end of each 'bare soil' cage to provide shelter for the parasitoids and a food source of flowers for the adult wasps.

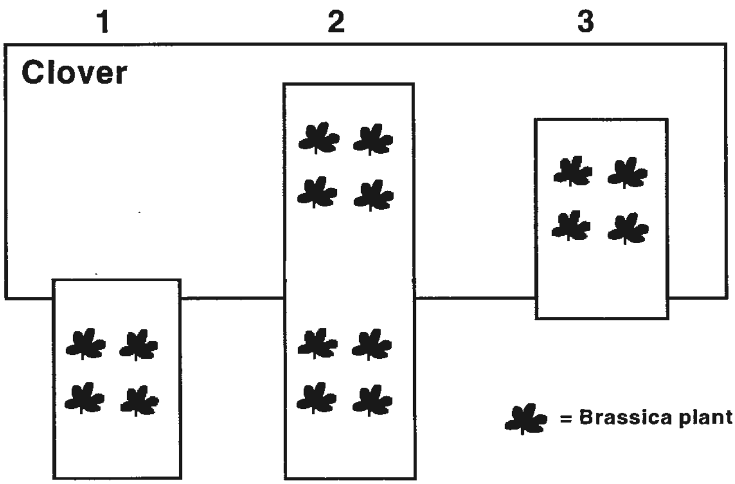

Figure 1. The three backgrounds enclosed by field cages (where shading indicates the presence of clover, all other areas being bare soil): 1 - bare soil, 2 – 50:50 bare soil and clover mixture, 3 – clover (see text for cage dimensions).

To balance the experimental design, a 10 cm strip of bare soil was left at the end of each 'clover' cage (Figure 1). The mixed background cage was setup as shown in Figure 1:2.

The following six parasitoid treatments were compared in each of the 3 backgrounds:

(1) un-inoculated host plant, no parasitoids (fly control)
(2) no parasitoids (parasitoid control)
(3) wasps released after 1 week (wasp wk. 1)
(4) beetles released after 1 week (beetle wk. 1)
(5) wasp wk. 1 + beetle wk. 1
(6) wasp wk. 1 + beetle wk. 2

Thus, there was a total of 18 background x treatment variables. The 18 variables were fully randomized within a block containing nine cages on either side of the clover strip. Three such blocks were fitted into the field plot.

Three weeks after the 'week 1' release of parasitoids, all of the cauliflower plants were harvested. The number of leaves, shoot weight and root weight were then recorded for each plant. A 10 cm core of soil was then taken from around the roots of each plant. Fly pupae were washed-out from the soil by flotation and examined for parasitism either visually or, when necessary, by dissection.

Data analysis

Shoot and root weights were log transformed [$y = \log10 (x + 0.375)$, where x = untransformed weight) and the number of leaves and number of pupae were square-root transformed [$y = \sqrt{}(x + 0.375)$, where x = untransformed weight] to stabilize variances, prior to analysis by ANOVA. The effect of background and treatment on the level of parasitism was assessed by analyzing the numbers of parasitized pupae using a generalized linear model (with binomial error distribution) to predict fitted proportions for each background/treatment combination.

Results

Plant size was not affected significantly by background, however, there was a significant effect of treatment on shoot and root weight ($P < 0.01$). This treatment effect was mainly due to the difference in size between those plants inoculated with fly eggs and the un-inoculated 'control' plants. The size of the plants in the cages where parasitoids were released was greater, in most cases, than in the cages where parasitoids were not released.

Cauliflower plants in clover backgrounds had significantly fewer leaves than those planted in bare soil ($P < 0.05$). The effect of treatment on leaf number was the same as that on plant size.

As a result of the initial inoculation of host plants with fly eggs, the number of fly pupae/plant at the end of the experiment was unaffected by background. Although as many as 19 fly pupae/plant were recovered, the mean for each of the 5 treatments inoculated with fly eggs ranged from 3-5 pupae/plant (Table 1). The variability in the total number of CRF pupae recovered per plant meant that it was not possible to compare the individual effects of all 18 background/treatment combinations. Consequently, the results were combined to determine the separate effects of background and treatment on parasitism of fly pupae by the wasp and the beetle.

Figure 2 shows that the background of clover had little effect on the level of parasitism by wasps or beetles. The only apparent effect of background was that the level parasitism by the beetle was higher in the larger cages, with both clover and bare soil areas, than in the smaller cages that were either all clover or all bare soil (Table 1).

Table 1. The numbers of fly pupae recovered and the percentage parasitized by wasps and beetles in the three different backgrounds.

	Bare soil		Bare soil:clover mixture		Clover	
Treatment	Total no. of pupae	Pupae/ plant	Total no. of pupae	Pupae/ plant	Total no. of pupae	Pupae/ plant
Fly control	5	0.4	2	0.1	2	0.2
Parasitoid control	56	4.7	129	5.4	30	2.5
T. rapae (wk. 1)	69	5.8	112	4.7	60	5.0
A. bilineata (wk. 1)	50	4.2	74	3.1	40	3.3
T. rapae (wk. 1) + *A. bilineata* (wk. 1)	42	3.5	134	5.6	42	3.5
T. rapae (wk. 1) + *A. bilineata* (wk. 2)	37	3.1	151	6.3	54	4.5
	% parasitism		% parasitism		% parasitism	
	A. bilineata	*T. rapae*	*A. bilineata*	*T. rapae*	*A. bilineata.*	*T. rapae*
Fly control	0	25	0	0	0	0
Parasitoid control	0	0	1	4	0	0
T. rapae (wk. 1)	12	46	0	53	3	45
A. bilineata (wk. 1)	2	0	18	0	8	0
T. rapae (wk. 1) + *A. bilineata* (wk. 1)	2	31	19	25	7	12
T. rapae (wk. 1) + *A. bilineata* (wk. 2)	3	30	21	22	17	35

The effect of treatment on pupal density and parasitism by the wasp and the beetle is shown in Table 1. From the two control treatments it is apparent that there was a low background level of both the fly and its parasitoids. When released separately, the wasp appears to be a more effective parasitoid than the beetle (maximum percent parasitized equals 53% and 18% respectively). When released together, whether synchronously or sequentially, the impact of the two parasitoids is not additive. In the presence of the beetle, the numbers of wasps emerging from the fly pupae were reduced (Table 1).

Discussion

The difficulties experienced in producing consistent results on how undersowing crops with clover affects host-finding by the parasitoids of cabbage root fly are similar to those discussed by Finch & Kienegger (1997) with reference to the effect of increased vegetational diversity on host-plant selection by pest insects. When investigating such interactions in the field it is essential to ensure that only one factor is varying at a time (Finch & Kienegger, 1997). A previous study with parasitoids (Langer, 1996) made no attempts to control the quality or size of the host plants, the density of the pest insects, or the number of wasps/beetles that could potentially parasitize them.

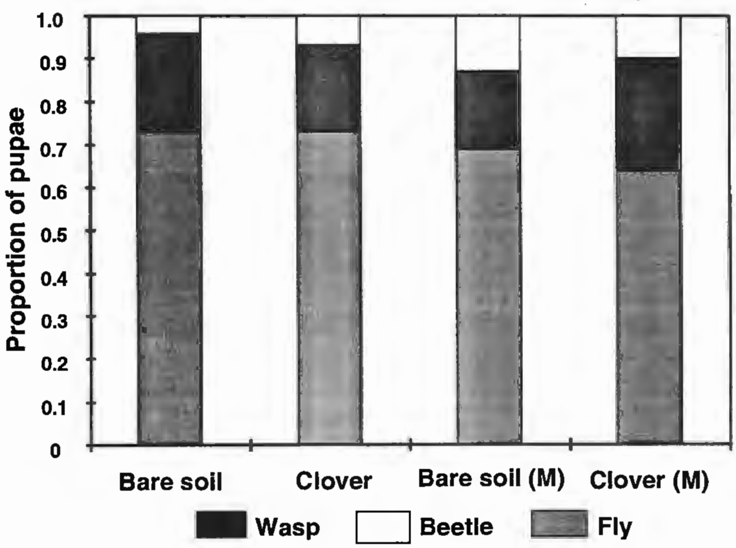

Figure 2. The relative proportions of unparasitized and parasitized fly pupae recovered from the soil around cauliflower plants in the different field-cages; bare soil, clover and a 50:50 mixture of bare soil and clover (M).

The techniques used in the present study, and the extremely short time interval over which the experiments were conducted, ensured that the influence of these variables was reduced to such an extent that the size of host plants, or the number of fly pupae associated with them, were not affected ($P \geq 0.05$) by a background of clover or bare soil. The only drawback to this method was that the field cages, used to exclude further infestation by pest insects, also prevented dispersal of released parasitoids and, to a lesser extent, excluded naturally-occurring enemies that may have competed with these parasitoids or possibly enhanced the levels of parasitism/predation. In the case of the wasp, it is unlikely that inclusion by the cage would have affected the results significantly, as this parasitoid displays a natural tendency to stay close to brassica plants in the field (S. Finch, personal observation).

Under these experimental conditions the current results show that parasitism of cabbage root fly by either the wasp or the beetle was not reduced significantly around brassica plants growing in clover compared to that around plants growing in bare soil. So, unlike the fly (Finch & Kienegger, 1997), the presence of clover does not appear to interfere with the host-finding ability of the parasitoids.

Release of both parasitoids into the same cage resulted in fewer fly pupae being parasitized successfully by the wasp compared to cages where only the wasps were released. This supports the results of Reader & Jones (1990), who observed that when fly pupae containing early-instar wasp larvae were attacked by beetle larvae the beetle usually killed the wasp before completing its own development.

The mechanisms involved in host finding behaviour by the wasp and the beetle are poorly understood. Laboratory studies have shown that female wasps respond to olfactory cues from the frass of fly larvae (Jones *et al.*, 1993). The results of the present study appear to support the growing evidence that both the wasps and the beetles use olfactory, rather than visual, cues as the key components during their host-finding behaviour. Such behaviour could explain the higher levels of parasitism recorded for the beetle in the larger field-cages (Table 1), where the presence of twice as many fly-infested brassica plants could result in an increased density of olfactory cues for host-finding.

Host-finding behaviour that depends upon the detection of chemical cues is often highly specific. This specificity may have broader implications for potential IPM strategies within brassica crops. If such volatile chemicals emanate from the potential host insect directly, or from the damage it does when feeding on the crop, the parasitoids would not be expected to be attracted to, or arrested in, areas where the pest is absent. If insecticide application resulted in the elimination of host-insects, then the subsequent impact of that insecticide on highly mobile populations of parasitoids would be minimal, as few individuals would be attracted into areas that were 'host-deficient'. Provided that insecticide was applied before peak immigration of parasitoids into the crop, this effectual separation of parasitoids and insecticide would increase their compatibility within future IPM strategies.

Résumé

Les effets de l'association d'une culture de chou et de trèfle sur la recherche de l'hôte par *Trybliographa rapae* et *Aleochara bilineata*, deux parasitoïdes de la mouche du chou *Delia radicum*

Une étude en cage a été faite au champ pour comparer le parasitisme de la mouche du chou, *Delia radicum* (L.), par l'hyménoptère *Trybliographa rapae* Westwood (Hymenoptera : Cynipidae) dans une parcelle de chou blanc (*Brassica oleracea* var. *botrytis* L.) cultivée sur sol nu et entourée par des choux fleurs associés à du trèfle (*Trifolium subterraneum* L.). Premièrement pour le lâcher du parasitoïde, les plantes ont été inoculées individuellement par des oeufs de *D. radicum* pour assurer un nombre initial de ravageurs semblable suivant le substrat. Le nombre de pupes de *D. radicum* parasitées soit par *T. rapae* soit par *A. bilineata* n'est pas affecté significativement par la présence de trèfle. Lorsque les parasitoïdes sont lâchés, le niveau de parasitisme par *T. rapae* était considérablement plus élevé que par *A. bilineata*. Cependant l'efficacité de *T. rapae* comme parasitoïde était réduite en présence de *A. bilineata*. Les résultats suggèrent que les deux parasitoïdes, à la différence de la mouche du chou, utilisent les repères chimiques plutôt que des repères visuels pour localiser l'hôte. Les implications de ce comportement de recherche de l'hôte sont discutées pour les futures stratégies de lutte intégrée (IPM).

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Time for development of *Trybliographa rapae*, an endoparasitoid of the cabbage root fly *Delia radicum*, at four constant temperatures

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Abstract: The time for the parasitoid *T. rapae* to complete its development within 2nd- and 3rd-instar larvae of *D. radicum* feeding on swedes was investigated at constant temperatures of 12, 15, 20 and 25°C. Throughout the tests, the relative humidity was 60±10% and the photoperiod was kept constant at 16h L:8h D. At 12, 15, 20 and 25°C, the time for *T. rapae* to develop from egg to adult within 2nd-instar fly larvae was 95, 75, 52, 42 days for the male wasps and 106, 81, 55, 48 days for the female wasps. At the same temperatures, the time required for development within 3rd-instar larvae was 86, 68, 51, 39 days for the male wasps and 91, 72, 51, 40 for the female wasps, respectively. Female wasps took longer to develop than the males in 2nd-instar fly larvae maintained at 12, 15 and 20°C and in 3rd-instar larvae maintained at 12, 15 and 25°C. The development rate of *T. rapae* increased with temperature. There was a strong correlation between temperature and the rate of wasp development within both larval instars of *D. radicum:* r_1^2 = 0,89 and r_2^2 = 0,94, for the 2nd- and the 3rd-instars, respectively. The threshold temperatures and degree-day requirements for *T. rapae* were respectively t_{01} = 1.40°C, K_1 = 1000 DD and t_{02} = 1.45°C, K_2 = 909 DD. The threshold temperature for development was lower for *T. rapae* than for *D. radicum.*

Key words: *Delia radicum, Trybliographa rapae,* day-degrees, threshold temperatures

Résumé

La durée de développement de *Trybliographa rapae*, un endoparasitoïde de *Delia radicum*, a quatre différentes températures constantes

La durée de développement de l'endoparasitoïde *T.rapae* sur le 2ème et le 3ème stade larvaire de *D.radicum* a été étudiée a différentes températures constantes. Quatre températures ont été testées 12, 15, 20, et 25°C, l' humidité relative étant de 60±10% et la photopériode de 16h L: 8h D. La température a un effet significatif sur la durée de développement du parasitoïde lorsque la ponte s'effectue dans le 2ème ou 3ème stade. La durée moyenne de développement de *T.rapae* de la ponte à l' émergence est de 95, 75, 52, et 42 pour les mâles, et est de 106, 81, 55 et 48 pour les femelles, sur les rutabagas infestés par des larves de 2ème stade, à 12, 15, 20, et 25°C respectivement. La durée moyenne de développement est de 86, 68, 51, et 39 pour les mâles, et est de 91, 72, 51 et 40 pour les femelles, sur les rutabagas infestés par des larves de 3ème stade, à 12, 15, 20, et 25°C, respectivement. La durée de développement des femelles est significativement plus élevée que celle des mâles, sur le 2ème stade larvaire, à 12, 15, et 20°C, et sur le 3ème stade larvaire, à 12, 15, et 25°C. La vitesse de développement de *T.rapae* augmente avec la température. Il y a une bonne correlation entre la vitesse de développement et la température: r_1^2 = 0.89 et r_2^2 = 0.94, sur les 2ème et 3ème stade, respectivement. La température seuil de développement et le nombre de degré-jour estimé pour *T.rapae* sont respectivement: t_{01} = 1.40°C, K, = 1000DD, t_{02} = 1.45°C, K_2 = 909DD. Il n'y a pas de différence significative entre les deux stades larvaires. La température seuil est inférieure à celle de *D.radicum,* qui varie entre 4 et 6 °C selon les auteurs.

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Effect of entomopathogenic nematodes from the genera *Steinernema* and *Heterorhabditis* on caterpillars of two pest insect species (*Pieris brassicae* L. and *Mamestra brassicae* L.) that damage cruciferous vegetable crops

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Abstract: Under laboratory conditions, entomopathogenic nematodes can be screened successfully against pest insect caterpillars using solutions of 1,000 nematodes/ml. Spraying leaf discs was slightly more effective (100% kill) than spraying the soil (90% kill). In the insectary tests, which involved more soil, the effects were only pronounced when the nematode inoculum was increased to 10,000 nematodes/ml. It took about seven days for the entomopathogenic nematodes applied to the soil to kill appreciable numbers of the test larvae. The nematodes sprayed onto the plant material killed the larvae sooner. Speed of kill is extremely important for pests like *Mamestra brassicae* and *Pieris brassicae*, as their caterpillars can cause severe crop losses in a relatively short time. The nematodes used in the experiments had no effect on either the species of Lumbricidae tested or on the slug *Agriolimax agrestis*. Of the nematodes used, the *Steinernema* species were more effective than the *Heterorhabditis* species. The species of *Heterorhabditis* obtained from Hungary were more effective than those from the USA. For plant protection it may be preferable to use nematodes adapted to domestic conditions. The success of control using entomopathogenic nematodes is influenced greatly by the moisture content of the soil. Applications of nematodes are recommended, therefore, only for soils where irrigation can be applied on a regular basis.

Key words: *Steinernema* spp., *Heterorhabditis* spp., *Pieris brassicae*, *Mamestra brassicae*

Introduction

Considerable emphasis is now being placed on finding plant protection methods that do not rely on the application of synthetic chemicals. One such method is to apply entomopathogenic nematodes. This approach is being tried in Hungary in co-operative experiments between the Plant Protection Institute of the PATE Georgikon Faculty of Agriculture and the Genetics Department at Eötvös Lóránt University. The former Institute collaborates with the Csongrád County Station of Plant Hygiene and Soil Conservancy to determine how best to apply the nematode preparations to commercial crops. The overall research is part of an American-Hungarian programme, and includes scientists from the Belstville Research Institute, University of Maryland, USA and the Wooster Research Institute, University of Ohio, USA.

The programme concentrates on entomopathogenic nematodes from the genera *Steinernema* and *Heterorhabditis*. Such nematodes have no harmful effect on vertebrates, are easy to produce in the laboratory, and can be applied without difficulty from either hand-held or machine-mounted sprayers.

Literature review

The *Steinernema* species live in symbiosis with bacteria belonging to the genera *Xenorhabdus*, while the *Heterorhabditis* species are associated with *Photorhabdus luminescens (Enterobacteriaceae)* (Akhurst & Boemare, 1990; Boemare *et al.*, 1993). The infective (dauer) juvenile nematodes penetrate into the cavity of the host animal (Poinar, 1967; Kaya & Gaugler, 1993), and then discharge bacteria which start to reproduce within the host animal. The bacteria destroy the host by subduing its immunosystem (Dunphy & Thurston, 1990). The nematodes feed on the bacteria and the host's tissues to develop and reproduce. The number of generations of nematodes produced depends on the amount of nutrients available. The individuals from the last generation of nematodes change into new infective juveniles before they abandon the host's cadaver and try to find a new insect host. The insect dies of septicaemia as its internal organs are destroyed by the bacteria and consumed by the nematodes. Hence the term: entomopathogenicity (Gaugler & Kaya, 1990; Poinar & Georgis, 1990).

Materials and methods

The studies were carried out in the Entomological Laboratory of the Plant Protection Institute of the Pannon University of Agricultural Sciences at the Georgikon Faculty of Agriculture.

In 1996, larvae of the pest insect species *Scotia segetum* Hübner, *Pieris brassicae* L. and *Mamestra brassicae* L. were used in the experiments. Besides these insects the slug *Agriolimax agrestis* L. and earthworms, *Lumbricidae*, were also tested. The insects required for the tests were obtained from laboratory cultures, whereas the slugs and earthworms were collected from the field. The infective larvae of the entomopathogenic nematodes were cultured in the laboratory, from a commercial nematode preparation supplied by the American Company BIOSYS.

In the experiments, two Hungarian species of nematode *Heterorhabditis bacteriophora* HH and *Heterorhabditis Bacteriophora* Cserszeg; Collected from the field (Lucskai and Mracek, 1996), were compared with five species/strains (*Heterorhabditis bacteriophora* USA, *Steinernema feltiae* 1048, *Steinernema feltiae* 1052, *Steinernema feltiae* A4 and *Steinernema glaseri*) obtained from various laboratory cultures. The laboratory experiments were done using solutions containing either 100 or 1,000 nematodes/ml. In contrast, in the insectary experiments the two solutions tested contained 1,000 and 10,000 nematodes/ml. Each treatment was replicated four times. In the laboratory experiments each test pot contained 100 g of soil and one insect larva whereas in the insectary tests, each pot contained 1,000 g of soil and 5 insect larvae. The soil used was a sterile mixture of 50% black earth and 50% sand. In the laboratory tests, 14 ml of water was added to each pot every two days to keep the soil moist throughout the test period. The nematodes were sprayed though a micropipette, 1) directly onto the soil surface, or 2) onto 5 cm diameter leaf discs resting on the soil surface. In the latter situation, the caterpillars ingested the nematodes as they ate the leaf discs.

All insects in the laboratory and insectary tests, were inspected on days 4, 7 and 14 after treatment. During these inspections, all of the dead larvae were placed into Petri dishes, left for several days, and then dissected to record those infected with nematodes (White, 1927).

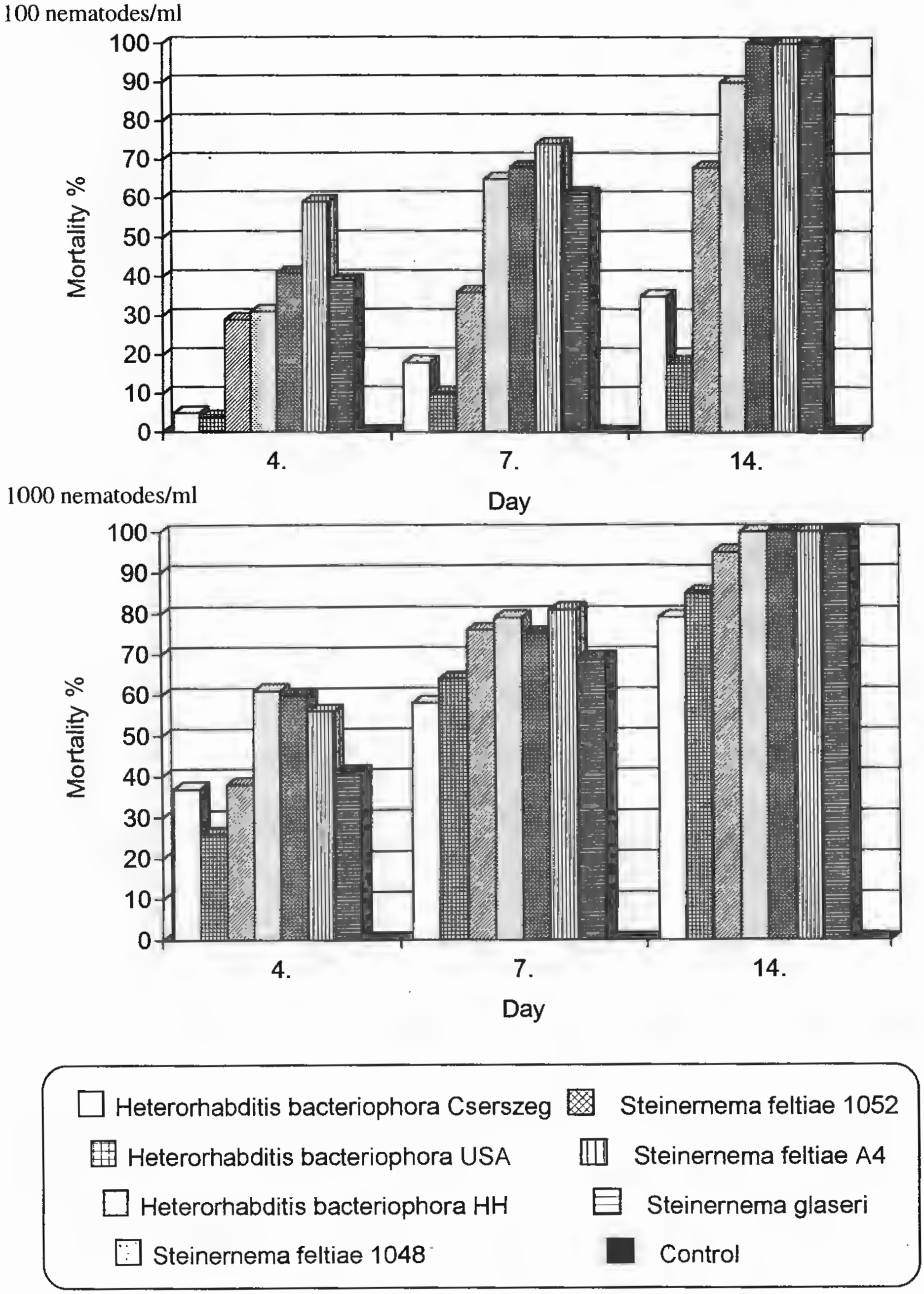

Figure 1. Effect of entomopathogenic nematodes on larvae of *Pieris brassicae* L. in laboratory tests (nematodes sprayed onto leaf discs).

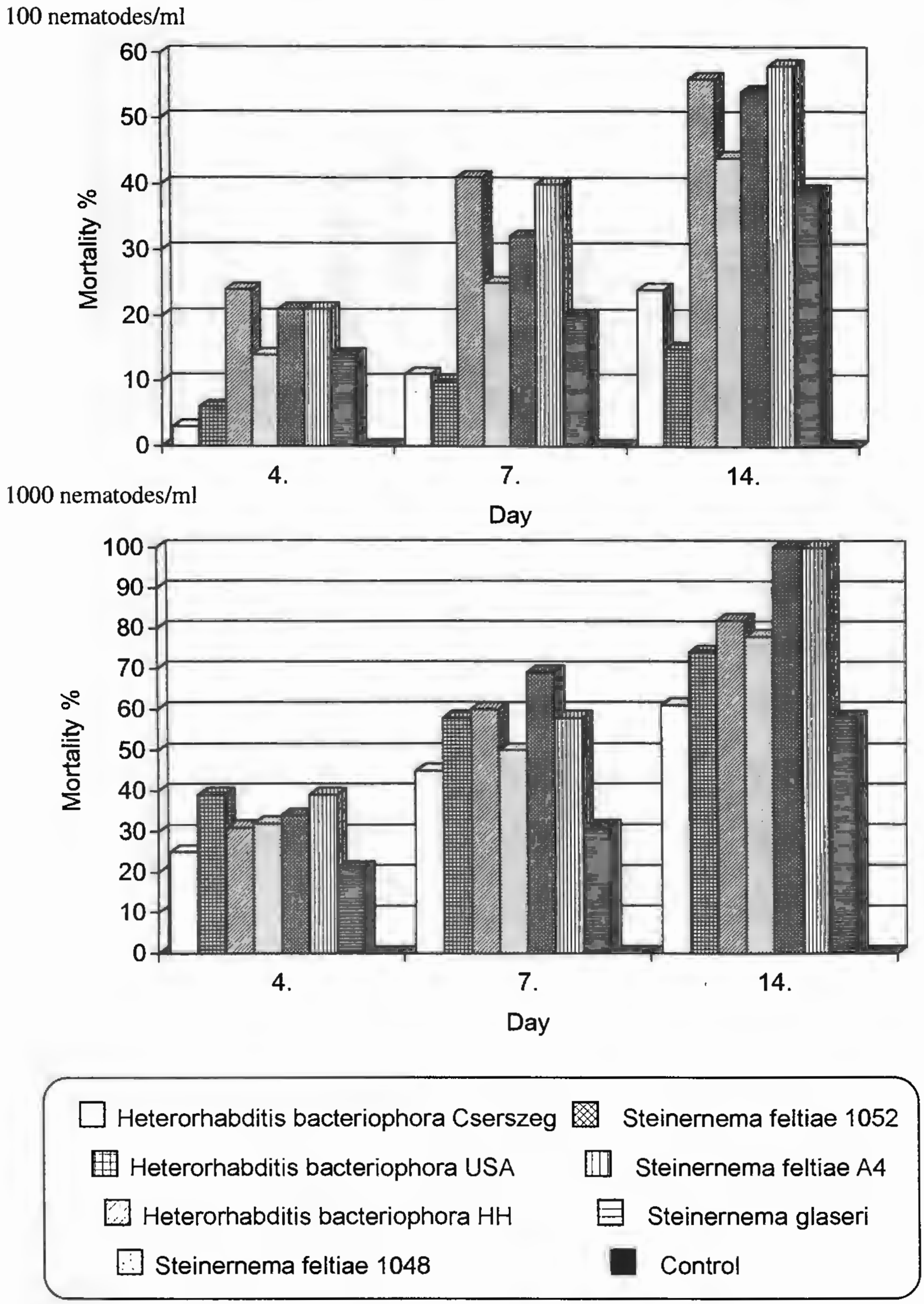

Figure 2. Effect of entomopathogenic nematodes on larvae of *Pieris brassicae* L. in laboratory tests (nematodes sprayed onto soil surface).

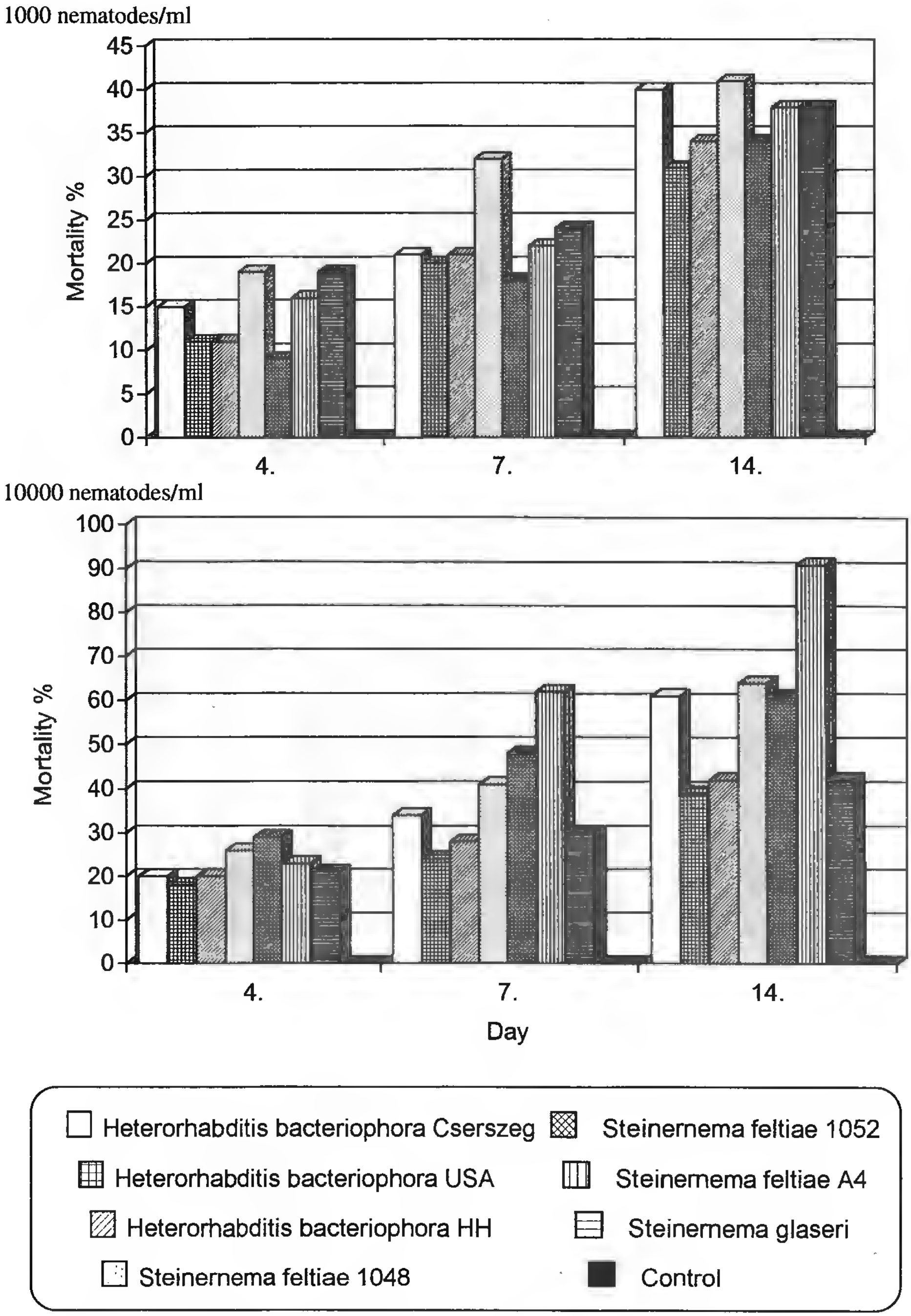

Figure 3. Effect of entomopathogenic nematodes on larvae of *Pieris brassicae* L. in insectary tests.

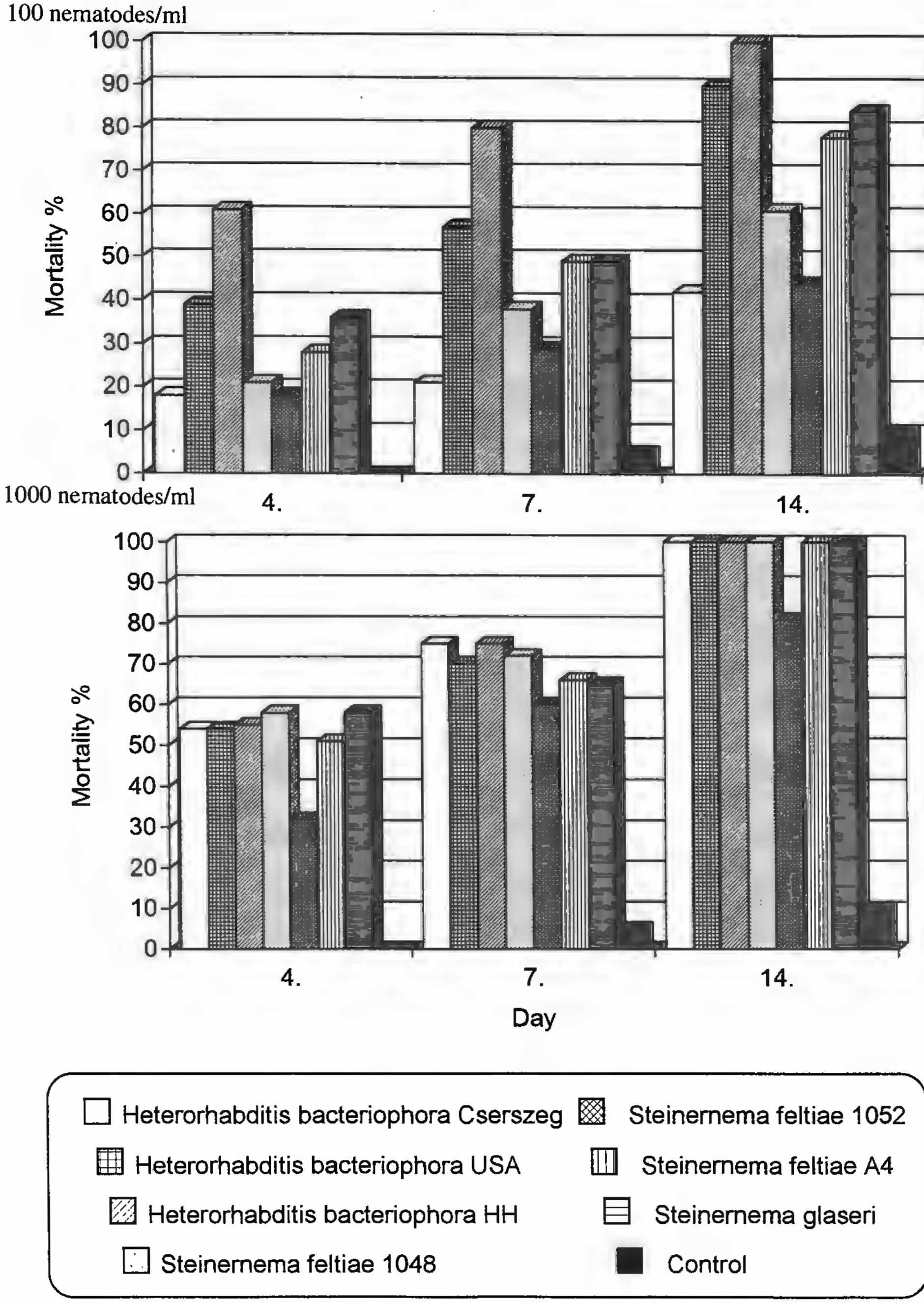

Figure 4. Effect of entomopathogenic nematodes on larvae of *Mamestra brassicae* L. in laboratory tests (nematodes sprayed onto leaf discs).

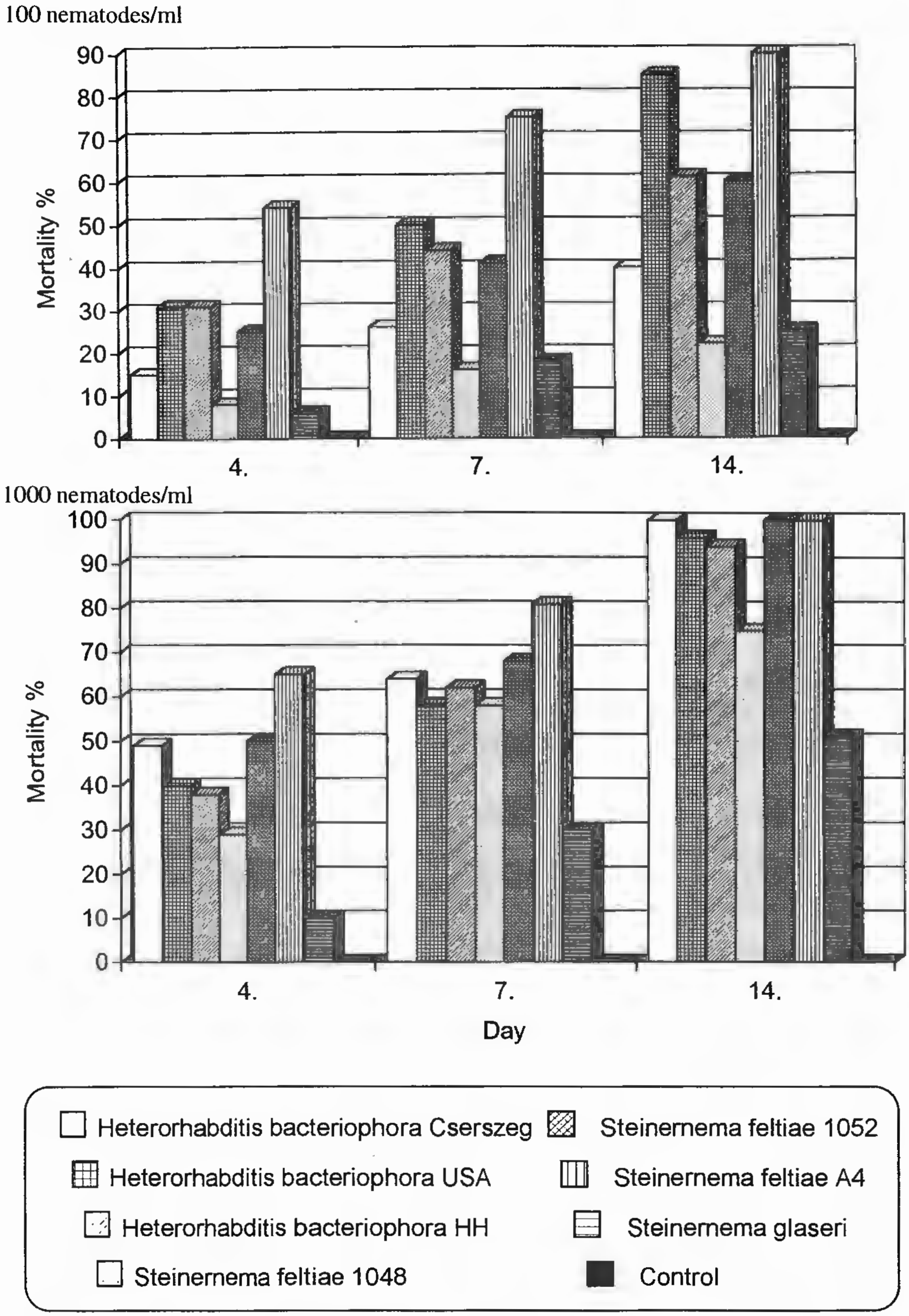

Figure 5. Effect of entomopathogenic nematodes on larvae of *Mamestra brassicae* L. in laboratory tests (nematodes sprayed onto soil surface).

Results

Experiments with the slug, Agriolimax agrestis, and* earthworms *(Lumbricidae)
The nematodes applied did not kill either the slugs or the earthworms used in the tests.

Experiments with larvae of the large cabbage white butterfly, Pieris brassicae
The results of the experiments are shown in Figures 1 – 3. In the laboratory tests, the best result was obtained by spraying the leaf discs, and at the higher concentration (1000 nematodes/ml) several of the nematodes preparations gave 100% kill after 14 days. Even at the lower concentration (100 nematodes/ml) the nematodes still killed about 70% of the *Pieris brassicae* caterpillars. When the nematodes were sprayed directly onto the soil, insect mortality was reduced considerably. Among the nematodes tested, the *Steinernema* species were the most effective. Of the *Heterorhabditis* species tested, those obtained from Hungary were generally more effective than those from the USA. In the insectary experiments, insect mortality was much lower than in the laboratory tests even when the higher concentration (10,000 nematodes/ml) of nematodes was applied. The *Steinernema* species tested were also more effective than the *Heterorhabditis* species in this experiment.

Experiments with larvae of the cabbage moth, Mamestra brassicae
The results of the experiments are shown in Figures 4 & 5. Spraying the foliage was more effective than spraying the soil. At the higher concentration tested, approximately 100% and 90% of the caterpillars were killed when the nematodes were sprayed onto the leaf disc or the soil, respectively. The insects that became infected with nematodes during feeding died sooner than those infected while resting on the soil. Generally, more than 60% of the nematodes were killed within seven days. All of the larvae of *Mamestra brassicae* tested were killed by six of the seven nematode preparations.

Résumé

Effet des nématodes entomopathogènes des genres *Steinernema* et *Heterorhabditis* sur les chenilles de deux espèces d'insectes ravageurs *Pieris brassicae* L. et *Mamestra brassicae* L. en cultures de crucifères légumes

En condition de laboratoire, les nématodes entomopathogènes peuvent être testés contre les chenilles d'insectes ravageurs, en utilisant des solutions titrant 1000 nématodes/ml. La pulvérisation de disque de feuille était plus efficace (100% de mortalité) que la pulvérisation de sol (90% de mortalité). Dans les tests réalisés en insectarium, qui implique plus de sol, les effets sont seulement prononcés quand l'inoculum était augmenté à la dose de 10000 nématodes/ml. Il faut environ sept jours pour que les nématodes entomopathogènes incorporés dans le sol tuent un nombre appréciable de larves. Les nématodes pulvérisés sur la plante tuent davantage les larves. La rapidité de la mort est extrêmement importante pour les ravageurs tels que *M. brassicae* et *P. brassicae* dont les chenilles peuvent provoquer des pertes sévères en très peu de temps. Les nématodes employés en expérimentation n'ont pas d'action sur les espèces de Lombricidae testées ou sur *Agrolimax agrestis*. Parmi les nématodes employés, les espèces de *Steinernema* furent plus efficaces que les *Heterorhabditis*. Les espèces d'*Heterorhabditis* obtenues de Hongrie sont plus efficaces que celles des USA. Pour la protection des plantes, il peut être préférable d'employer des nématodes adaptés aux conditions locales. Le seuil de lutte par des nématodes entomopathogènes est fortement influencé par l'humidité du sol. Les applications de nématodes sont recommandées toutefois seulement dans des sols ou l'irrigation peut être appliquée de façon régulière.

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Development and mortality of the nymphal stages of the predatory bug *Macrolophus pygmaeus*, when maintained at different temperatures and on different host plants

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Abstract: The rate of development and mortality of the nymphs of *Macrolophus pygmaeus* Rambur (Hemiptera: Miridae) were studied in the laboratory. The nymphs were maintained on both egg-plants and pepper-plants, in the presence and absence of the aphid *Myzus persicae* (Sulzer). The experiments were done at 15, 20, 25, 30 and 35°C in a growth cabinet maintained at 65% RH and 16:8 hours L:D. Twenty nymphs of the predator were included in each treatment. The nymphs completed their development successfully at all temperatures, in the presence or absence of aphids, except when aphids were not present and the nymphs were kept on pepperplants maintained at 35°C. The nymphs took longer to develop when aphid prey was not available. On both host plants, nymphs developed most rapidly at 30°C irrespective of whether prey was, or was not, available. In the presence of prey the nymphs developed at the same rate on both host plants. When prey was not available the nymphs developed faster on egg-plants than on pepper-plants. The mortality rates of the nymphs were highly variable. The highest mortality was recorded at 35°C when prey was not available. When aphid prey was available the rates of nymphal mortality were similar on both host plants. When prey was not available, more nymphs died on the pepper-plants than on egg-plants. The nymphs of this predator can develop at a variety of temperatures, even when there is no aphid prey. Egg-plants are more suitable as a host than pepper-plants.

Key words: *Macrolophus pygmaeus*, *Myzus persicae*, egg-plant, pepper plants

Introduction

Species of the genus *Macrolophus* (Hemiptera : Miridae) are active predatory bugs and feed on soft bodied insects such as whiteflies and aphids. They are found commonly on many cultivated crop plants such as tomato, egg-plant, pepper-plant, cucumber and French beans (Alomar *et al.*, 1990; Goula & Alomar, 1994; Perdikis & Lykouressis, 1996). The two most well-studied species of the genus are *Macrolophus caliginosus* Wagner and *Macrolophus pygmaeus* Rambur. They are difficult to distinguish from each other and are considered by some authors to be part of a species complex (Goula & Alomar, 1994) and so their taxonomic status is still under review (Goula & Alomar, 1994; Perdikis & Lykouressis, unpubl. Data). *M. caliginosus* has been used with encouraging results as a biological agent for controlling certain pests of tomato crops (Roditakis & Legakis, 1989; Alomar *et al.*, 1991; Sampson & King, 1996). In a laboratory study done on certain aspects of the biology of *M. caliginosus* (Fauvel *et al.*, 1987), it was found that the developmental rates of the nymphs were higher when *Trialeurodes vaporariorum* (Westwood), *Aulacorthum circumflexum* Buckton and *Mysus persicae* (Sulzer) were available as part of the predators diet. In field studies done in central Greece (Perdikis & Lykouressis, 1996; Lykouressis, Perdikis & Chalkia, unpubl. Data) *M. pygmaeus* was shown to be the major predator suppressing populations of aphids, mainly *Macrosiphum euphorbiae* (Thomas) and *M. persicae*, in crops of fresh-market and processing tomatoes. High numbers of nymphs and adults of this predator were recorded, in both studies, towards the end of the growing season.

In this study, experiments were done to show how changes in temperature, prey items and host plants affected the rates of development of the nymphs of *M. pygmaeus*. The aim was to obtain the type of information required to develop a robust programme of biological control.

Materials and methods

In September 1994, a laboratory culture of *M. pygmaeus* was started using a batch of insects collected from a crop of processing tomatoes. The *M. pygmaeus* were then reared continuously on eggplants (cv. Bonica), infested with *M. persicae*, in a glasshouse maintained at about 23°C. In the laboratory tests, newly-emerged nymphs of *M. pygmaeus* were kept individually in 9 cm diameter plastic Petri dishes. The top of each dish had a 3 cm diameter hole covered with muslin for ventilation. The bottom of each dish, was covered with a layer of cotton wool, moistened with water, on which a leaf from a host-plant was placed upside-down. Half of the test leaves were infested with aphids, the rest were aphid-free. The host plants tested were egg-plant (cv. Bonica) and green pepper-plant (cv. Vidi). The rate of nymphal development of *M. pygmaeus* was studied on both plants in the presence and absence of aphid prey (*M. persicae*). Twenty nymphs of the predator were used for each treatment. The test Petri dishes were kept at 15, 20, 25, 30 and 35°C, 65% RH and 16:8 hours L:D. In all tests the leaves were renewed each day except for the tests done at 35°C, in which leaves were renewed every 12 hours. The stage of nymphal development and any mortality were recorded each time the leaves were changed. Keys (Perdikis & Lykouressis, 1997) were used to identify the various nymphal stages. All data were analyzed using t-test (P=0.05) and linear contrast analysis.

Results

A high proportion of all nymphs developed to the adult stage. However, all of the nymphs died when placed onto pepper leaves and kept at 35°C, without prey. At all temperatures studied, the nymphs took less time to develop when prey was available (Figure 1). Significant differences were found in the two host plants, egg-plant (F_{ratio}=96.65 with 1 and 136 d.f., P<0.001) and pepper-plant (F_{ratio}=247.44 with 1 and 123 d.f., P<0.001). Significant differences were not obtained, when the nymphs were kept on 15°C and 30°C (Tables 1 & 2). The nymphs developed fastest at 30°C and slowest at 15°C. (Figure 1).

When prey was available, no differences were found in the times required for nymphal development on either egg-plants or pepper-plants. However, at 35°C, the nymphs required less time to complete their development on egg-plants than on pepper-plant (Figure 2). In contrast, when prey was not available, the time required for the nymphs to complete their development at 15°C and 30°C, was shorter on eggplant than on pepper (Figure 2). The rates of nymphal mortality varied from 5-100%, between the differ4ent temperatures, host plants and availability of prey (Figure 3). Generally, more nymphs died when no prey was available. The highest (100%) mortality occurred at 35°C on the pepper leaves that were not infected with aphids.

However, a few nymphs developed as far as the fourth nymphal stage. High mortality occurred also at 35°C when prey was available on the pepper leaves and when prey was present/absent on the eggplant leaves. On both host-plants, the lowest mortality occurred at 20°C and 25°C, irrespective of whether aphids were present or not (Figure 3).

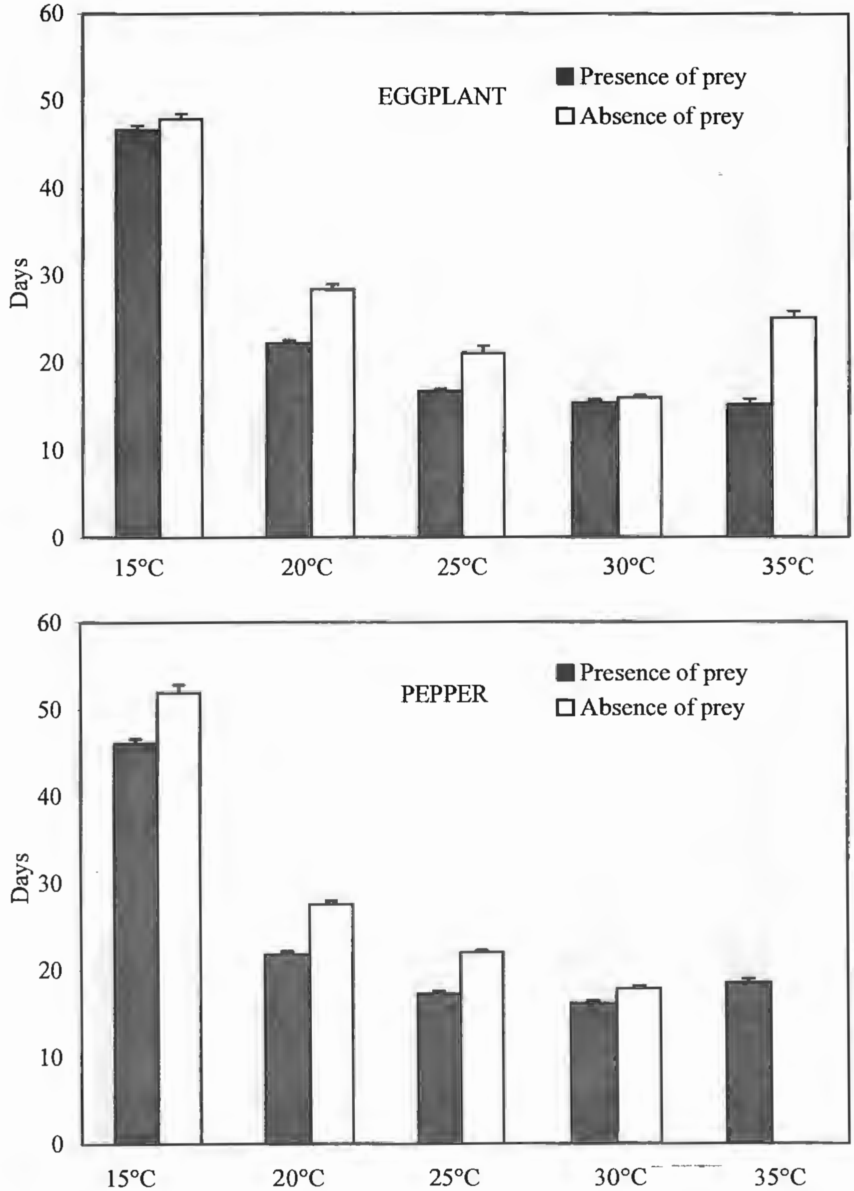

Figure 1. Period of development in days (X±SE) of the nymphal stages of *Macrolophus pygmaeus* on egg-plant and pepper plants in the presence and absence of its prey *Myzus persicae* at five different temperatures.

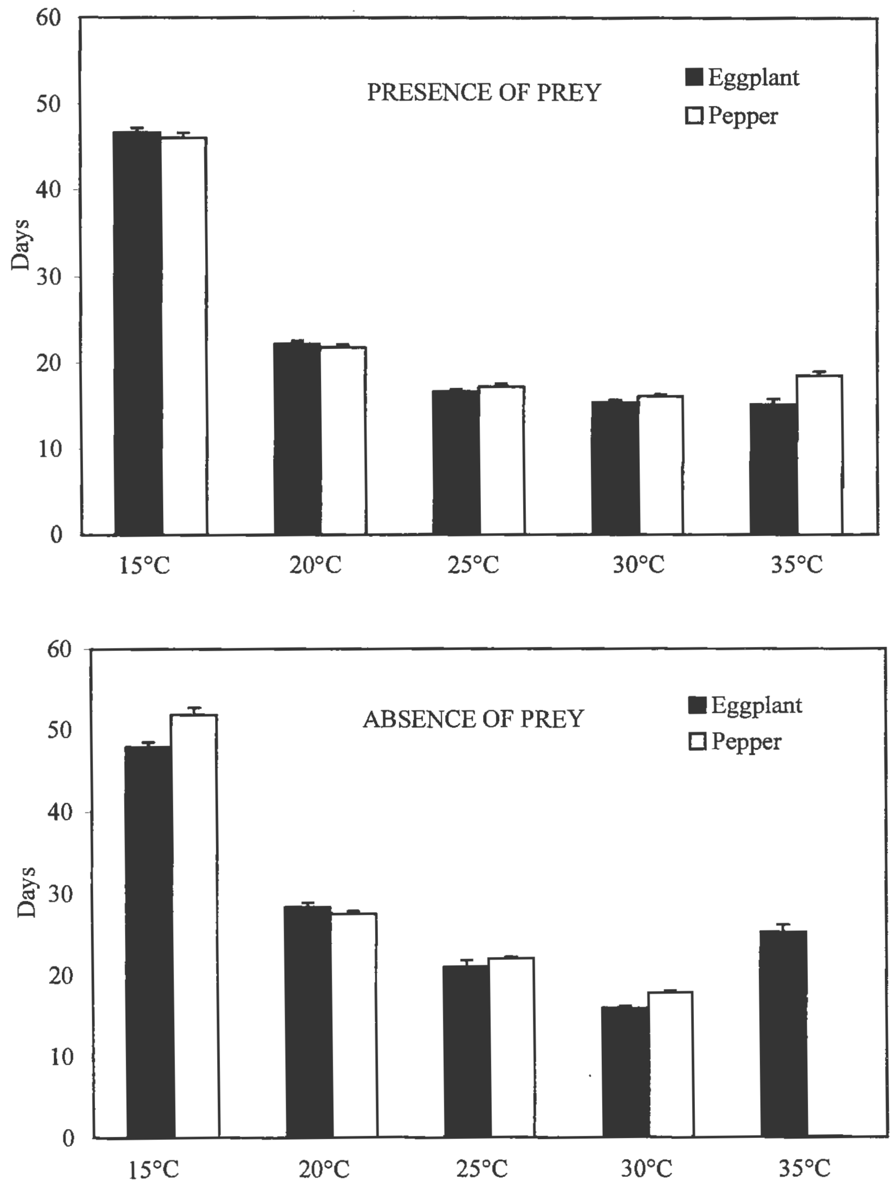

Figure 2. Period of development in days (X±SE) of the nymphal stages of *Macrolophus pygmaeus* on egg-plant and pepper plants in the presence and absence of its prey *Myzus persicae* at five different temperatures.

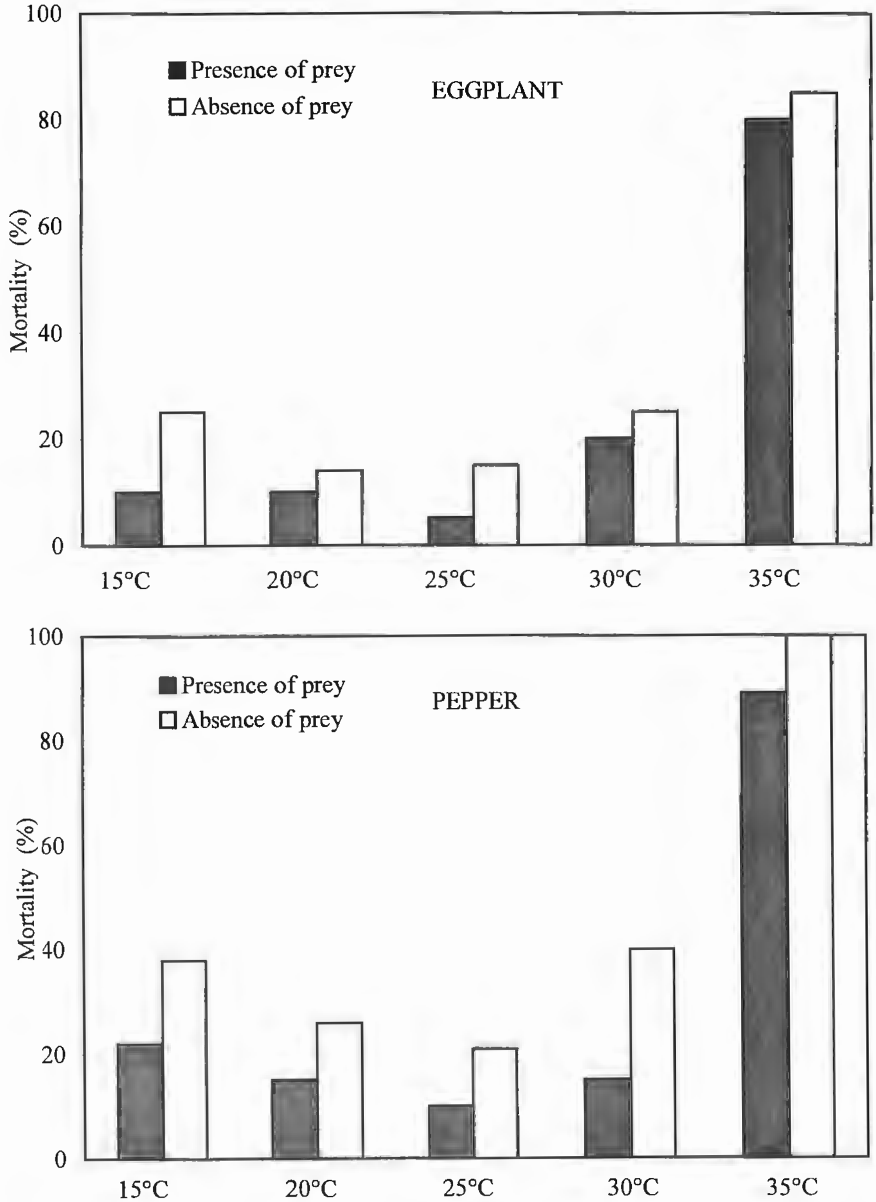

Figure 3. Percentage of mortality of the nymphal stages of *Macrolophus pygmaeus* on eggplant and pepper plants in the presence and absence of its prey *Myzus persicae* at five different temperatures.

Table 1. The numbers (X±SE) of days required for the predatory bug *Macrolophus pygmaeus* to complete its nymphal stage on eggplants in the presence and absence of its prey, the aphid *Myzus persicae*.

Temperature (°C)	Presence of prey	Absence of prey	t- value
15	47±0.5	48±0.6	1.6**
20	22±0.4	28±0.6	8.6**
25	17±0.2	21±0.8	5.3**
30	15±0.3	16±0.3	1.7**
35	15±0.6	24±1.1	7.9***

** P<0.01, ***P<0.001

Table 2. The numbers (X±SE) of days required for the predatory bug *Macrolophus pygmaeus* to complete its development on pepper plants in the presence and absence of its prey, the aphid *Myzus persicae*.

Temperature (°C)	Presence of prey	Absence of prey	t- value
15	46±0.6	52±0.9	5.6***
20	22±0.4	28±0.3	11.3***
25	17±0.3	22±0.3	14.6***
30	16±0.3	18±0.2	4.1***

***P<0.001

Discussion

The nymphs of *M. pygmaeus* developed into adults at temperatures ranging from 15°C-35°C. The most suitable temperatures for nymphal development were 25°C - 30°C and the least suitable was 15°C. Similar results have been published for the period of nymphal development of *M. caliginosus* (Fauvel *et al.*, 1987). These authors found that, at 30°C, the period of development of nymphs, preying on *T. vaporariorum* on tomato leaves, was slightly shorter than that at 25°C and much shorter than those at the lower temperatures tested. The period of nymphal development was shorter, in almost all cases, when aphid prey were present. Hence, the aphid *M. persicae* appears to be a nutritive source of food for the nymphs of *M. pygamaeus*. Tsybuslkaya & Kryzhanovskaya (1980) also reported that *Macrolophus nubilus* (H.-S.) developed much faster when its prey *T. vaporariorum* was present on tobacco leaves.

In the present study, the nymphs of *M. pygmaeus* completed their development at a wide range of temperatures (Figure 1) in the absence of prey. Malausa *et al.* (1987) observed that *M. caliginosus* could feed on the juices from tomato plants when prey were scarce, but did not indicate whether the nymphs could complete their development in the absence of prey. Alomar *et al.*, (1990) stressed the need to investigate whether the phytophagous habits of mirids are essential for their development and survival. The present results indicate that the contribution from the host-plant is considerable and that the nutrients obtained from egg-plants seem to be more suitable than those from pepper-plants for the nymphal development of *M. pygmaeus*.

In conclusion, nymphs of *M. pygmaeus* develop most rapidly at temperatures of about 30°C, which occur commonly in glasshouses around the Mediterranean region. The nymphs can survive and complete their development at high (35°C) and low (15°C) temperatures even when prey is not present. Such attributes mean that nymphs of *M. pygmaeus* appear to be a very promising biological control agent for use under glasshouse conditions and/or outdoors.

Résumé

Développement et mortalité des stades nymphaux de la punaise prédatrice *Macrolophus pygmaeus* maintenus à différentes températures et sur différentes plantes hôtes.

Les taux de développement et de mortalité des nymphes de *Macrolophus pygmaeus* Rambur (Hemiptera : Miridae) sont étudiés en laboratoire. Les nymphes sont maintenues à la fois sur des aubergines et des poivrons, en présence et en absence de puçerons *Myzus persicae* (Sulzer). Les expériences sont réalisées à 15, 20, 25, 30 et 35°C dans des enceintes climatisées maintenues à 65% d'humidité et 16 :8 heures L :D. 20 nymphes de prédateurs sont placées à chaque conditions. Les nymphes achèvent leur développement avec succès à toutes les températures et en présence ou en absence de puçerons, sauf lorsque les puçerons sont absents sur les poivrons à la température de 35°C. Les nymphes prennent plus de temps pour se développer aux basses températures lorsque les pucerons sont absentes. Sur les deux plantes hôtes les nymphes se développent plus rapidement à 30°C sauf si les proies sont, ou ne sont pas, présentes. En présence de proies, les nymphes se développent aux mêmes taux sur les deux plantes. Quand il n'y a pas de proies, les nymphes se développent plus rapidement sur les aubergines que sur les poivrons. Les taux de mortalités sont excessivement variables. La mortalité la plus élevée est obtenue à 35°C en absence de proies. Quand les pucerons sont utilisables la mortalité des nymphes est identique sur les deux plantes. Quand les proies sont absentes il y a davantage de mort sur les poivrons que sur les aubergines. Les nymphes de ce prédateurs peuvent se développer même lorsqu'il n'y a pas de proies dans une large gamme de températures. L'aubergine est plus intéressante comme plante hôte que le poivron.

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Preliminary observations on *Diadegma fenestralis* a parasitoid of the diamond-back moth, *Plutella maculipennis*

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Abstract: In 1995–1997, larvae and pupae of the diamond-back moth were collected from cabbage plants grown on an experimental farm near Kraków in southern Poland. To estimate the level of parasitization in the field population, each insect collected was reared in an individual glass tube. Although *Diadegma fenestralis* Holmgr. was by far the commonest parasitoid that emerged from the larvae, six other species of parasitoid belonging to the Ichneumonidae and Braconidae also emerged. The levels of parasitism varied from 0 to 100%. High rates of parasitism were recorded throughout the whole period of infestation by the diamond-back moth, which occurred throughout July and August. No differences were found in the rates of parasitization of larvae collected from cabbage plants grown in a monoculture compared to those collected from cabbage plants intercropped with white clover. However, the application of insecticide decreased both the total number of parasitoids recorded and the levels of parasitization.

Key words: *Plutella xylostella, Diadegma fenestralis,* undersowing, white clover

Introduction

Cruciferous plants are the major field vegetable crops in Poland and among them, the late cultivars of white head cabbage are traditionally the most important crop. Several pest Lepidoptera attack cabbage crops during July and August. The most serious damage is caused by larvae of the small white butterfly (*Pieris rapae* (L.)), the diamond-back moth (*Plutella maculipennis* (Curt.)) and the cabbage moth (*Mamestra brassicae* (L.)). Most growers in Poland protect their cabbage crops by applying sprays of the recommended insecticides. Only a few growers use any form of economic threshold to decide whether or not to treat, and fewer still are able to recognise the parasitoids found attacking the main pest insects. The aim of this study was to determine the levels of parasitism of diamond-back moth larvae during the growing season and to determine the main species of parasitoid involved.

Materials and methods

Diamond-back larvae were collected routinely from cabbage plants growing in experimental plots on a farm located near Kraków in southern Poland. Plots of late white head cabbage (cv. Kamienna Glowa) were subjected to one of the following three treatments:

1) cabbage intercropped with white clover
2) cabbage grown in a monoculture and sprayed with diazinon, phosalon, pirimicarb
3) cabbage grown in a monoculture and left unsprayed .

Last-instar larvae and pupae of the diamond-back moth were collected weekly in 1996, and every 10 days in 1997, from the beginning of July to the end of August. Each insect collected was reared in a separate glass specimen tube. In 1995, only one sample was taken.

Parasitoids obtained in 1995 and 1996 were identified by Dr B Miczulski from the Agricultural University of Lublin.

Results

Diadegma fenestralis (Hymenoptera, Ichneumonidae) was the most numerous parasitoid recovered from the diamond-back larvae both in 1995 and 1996 (Table 1). In 1995, all of the parasitoids, apart from one, were *Diadegma fenestralis.* The odd specimen was the braconid parasitoid, *Apanteles laevigatus* Ratz. Several other species were recorded in 1996, but they made up less than 25% of the total.

Table 1. Species of parasitoid reared from pupae of the diamond-back moth *Plutella maculipennis* Curt. collected from different cabbage crops in Mydlniki in 1996.

Species	1995	1996
	Number of parasitoids	
Diadegma fenestralis.	65	37
Thyraella collaris Grav.	-	2
Mesochorus sp.	-	1
Apanteles longicauda Wesm.	-	9
Apanteles laevigatus.	1	-
Apanteles sp.	-	1
Tetrastichus sokolovskii	-	12*
Total	66	62

*emerged from one pupa

Although the level of parasitism was generally high during the growing season, it varied from 0 to 100% in some occasions (Table 2 & 3). The mean parasitism of the diamond-back larvae in 1996 was 94%. In 1997, it was lower (Table 3) and varied from 44% – 75%, probably because there was a period of heavy rainfall during July and August. Parasitism was high as soon as the diamond-back moth larvae were found on the plants (Table 2 & 3). No differences were found between the level of parasitism of the larvae collected from the cabbages in the monoculture and those intercropped with white clover (Table 4). The application of insecticide reduced significantly both the number of pest insects present and the overall levels of parasitism.

Table 2. The numbers and percentages of diamond-back moth (*Plutella maculipennis* Curt.) larvae parasitized on late cabbage in Mydlniki (1996).

Date	Number of pupae collected	Number of pupae parasitized	Parasitization (%)	Number of moths reared	Number of pupae dead
1 July	3	-	0	3	-
8 July	8	5	63	2	1
15 July	11	8	73	-	3
22 July	20	18	90	-	2
29 July	43	41	95	2	-
7 Aug	33	33	100	-	-
12 Aug	30	25	83	2	3
19Aug	15	9	60	-	6
26 Aug	9	2	22	-	7
3 Sept	3	2	7	1	-
Total	175	143	94	10	22

Table 3. The numbers and percentages of diamond-back moth larvae *Plutella maculipennis* Curt.) parasitized on late cabbage in Mydlniki (1997)

Date	Number of pupae collected	Number of pupae parasitized	Parasitization (%)	Number of moths reared	Number of pupae dead
2 July	-	-	-	-	-
12 July	18	8	44	10	-
22 July	75	54	75	18	3
2 Aug	77	41	65	22	4
12 Aug	224	112	52	102	10
11 Aug	50	33	69	15	2
30 Aug	16	12	75	4	2

Table 4. The numbers and percentages of diamond-back moth larvae parasitized on late cabbage
in Mydlniki (1995 – 1997).

Date of observation	Type of cultivation					
	Cabbage without insecticides		Cabbage intercropped with white clover		Cabbage with insecticides	
	No. of parasitized larvae					
	Total	%	Total	%	Total	%
24 July 1995	78	81	39	90	4	29
22 July 1996	48	94	48	100	1	14
12 August 1997	73	53	39	70	-	-

Discussion

In recent years, larvae of the diamond-back moth have become the major pest of cabbage crops in southern Poland. Most larvae were recorded during the second half of July and the beginning of August. Although formerly considered a minor pest in temperature areas, diamond-back moth has now become a major pest in these regions, due mainly to its ability to develop resistance to insecticides (Idris & Grafius, 1993). Until recently in Poland, little attention has been paid either to this pest or its parasitoids. Only Lagowska (1981) described the parasitoids reared from diamond-back larvae collected near Lublin (eastern Poland). In this research *D. fenestralis* was the dominant species and significantly reduced larval infestations. Although several other species were reared from the diamond-back larvae collected near Lublin, most of these species differed from those collected near Kraków. In Canada, Putman (1968) studied the competition between *D. insularis* and *Microplitis plutellae* Muesebeck, two parasitoids of the diamond-back moth. He found that increasing temperature from 20°C favoured slightly *D. insularis*, which might explained its dominance over the other parasitoid. Bolter and Laing (1983) also found that *Diadegma insularis* was more competitive than the other parasitoids. The results of research conducted in many other countries indicate that different species of *Diadegma* also parasitize diamond-back larvae. *D. insularis* is the most effective parasitoid in North America (Harcourt, 1960; Bolter & Laing, 1983; Lasota & Kok, 1986). *D. semiclause* in England (Hamilton, 1979; Waage, 1983) and France (Rahn & Chevallereau, 1996) and ., *fenestralis* in India (Abraham & Padmanaban, 1968). Furthermore, *D. semiclause* is used successfully in Indonesia against larvae of the diamond-back moth in IPM programmes being used in cabbage crops (Sastrosiswojo, 1996).

Résumé

Observations préliminaires sur *Diadegma fenestralis* un parasitoïde de la teigne *Plutella maculipennis*

En 1995 - 1997, les larves et les chrysalides de la teigne des crucifères sont récoltées sur des plants de choux cultivés en ferme expérimentale près de Cracovie dans le sud de la Pologne. Pour estimer le taux de parasitisme de la population provenant des champs, chaque insecte récolté est placé individuellement dans un tube de verre. Bien que *Diadegma fenestralis* Holmgr. soit de loin le parasitoïde le plus fréquent qui émerge des larves, six autres espèces de parasitoïdes appartenant aux Ichneumonidae et au Braconidae ont également émergées. Les taux de parasitismes variaient de 0 à 100%. Des taux élevés de parasitisme furent notés pendant toute la période d'infestation de la teigne qui s'étend de Juillet à Août. Aucune différence n'a été trouvée dans les taux de parasitisme des larves récoltées sur les plants de choux cultivés en monoculture comparés à ceux des choux cultivés en association avec du trèfle. Cependant, l'application d'insecticide a réduit à la fois le nombre de parasitoïdes et les taux de parasitisme.

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Undersowing Crops with Clover

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The influence of undersown clover and different fertiliser levels on infestations of the onion thrips in leek crops

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Abstract: The numbers of onion thrips found in a leek monocrop and a leek/strawberry clover intercrop were recorded to determine whether there was any interaction between intercropping and the amounts of fertiliser applied in suppressing *Thrips tabaci* populations in leek crops. In both cropping systems, synthetic nitrogen was applied at the rates of 0, 50 and 150 kg/ha. Hence there were much lower concentrations of nitrogen in the green leaves and shaft of the leek plants in the non-fertilised plots. Thrips densities were lower in the intercropped leek plots than in the monocropped plots. The numbers of thrips recorded were not correlated with the amounts of nitrogen present in the foliage or shaft of the leek plants. Unlike the response of other pest species to improved plant quality, *T. tabaci* populations appeared not to be influenced by such changes.

Key words: *Thrips tabaci, Allium porrum* under sowing, *Trifolium fragiferum*

Introduction

Intercropping helps to improve weed control, insect control, disease control and soil fertility (Trenbath, 1993). Despite such advantages, intercropping has not been adopted widely in vegetable production mainly because the competition between the intercrop and the main crop is sometimes severe (Ilnicki & Enache, 1992). Efforts to reduce this competition, have included selecting less-competitive plant species, or cultivars, as the intercrop, widening the strips of bare soil for the main crop, and/or applying additional fertiliser (Letourneau, 1995).

Current theories in agricultural ecology suggest there could be conflicting outcomes regarding pest control if additional fertiliser is applied to systems involving intercropping (Costello, 1995). Pest levels should be lower in the intercropped than in the monocropped systems (Andow *et al.*, 1986). However, increased fertiliser aids plant growth and this could eliminate the nutritional constraints on growth and reproduction by the herbivorous insects which could result in increased pest levels (Letourneau, 1995).

In this study, we compared the levels of infestation of onion thrips in leek monocrops and leek/clover intercrops subjected to different rates of fertiliser. This was done to determine whether the suppression of thrips populations in leek crops was affected by any interaction between intercropping and the amounts of fertiliser applied.

Materials and methods

During the summer of 1996, a field trial was done at the Institute for Agrobiology and Soil Fertility (AB-DLO) near Wageningen, where the soil type is a sandy soil. The experiment was a randomised complete block design. Each block consisted of two 6 x 30m plots and was replicated four times. The two main plot factors, which consisted of plots of leeks (*Allium porrum* L., cv. Tadorna, an autumn-harvestable cultivar) that were, and were not, undersown with strawberry clover (*Trifolium fragiferum* cv. Palestine) were assigned randomly to plots within the blocks. The subplot factors consisted of three levels of nitrogen N_0, N_1 and N_2, (0, 50 and 150 kg/ha) in addition to the standard application of 50 kgN/ha that was applied when clover was drilled. Each subplot measured 6 x 3 m. Throughout the experiment, the 2m-wide alleyways left between the test plots were kept free of vegetation.

The strawberry clover was sown at the end of March at the rate of 15 kg seed/ha. The five rows of clover in each plot were spaced 12 cm apart. The leek plants were transplanted on 9 July and were spaced 9 cm apart within the row and 75 cm apart between the rows. All plots were sprinkle irrigated, when the PF (leaf water potential) measured for each subplot reached 2.8. When necessary, the clover crop was suppressed by mowing. The fertilizer subplots also received synthetic nitrogen every two weeks at the pre-determined treatment levels of; N_0 = no additional nitrogen, N_1 = equivalent to the rate of 50 kg/ha, N_2 = equivalent to rate of 150 kg/ha.

Observations on thrips

From the day of transplanting, counts were made each week of the numbers of larvae and adults of *Thrips tabaci* Lindeman, present on five plants selected at random. Each plant was examined leaf by leaf to obtain an accurate count of the numbers of both larva and adult thrips (Theunissen & Schelling, 1996).

Total thrips pressure was expressed as;

$$\sum_{i=1}^{k-1} \frac{(N_{i+1}-N_i)}{2} (T_{i+1}-T_i)$$

where N = the total number of thrips, and T = the observation day.

Nitrogen

Ten leek plants were selected per subplot. On the three sampling dates, 4, 8 and 16 weeks after planting, the plants were cut at soil level and taken to the laboratory for processing. All samples were weighed fresh, dried at 60^0C, re-weighed and then analysed for their nitrogen content.

Statistical analysis

The nitrogen contents of the leaf and shaft of the leek plants and thrips pressure were analysed using an ANOVA in which the clover treatment was a main factor. The levels of significance are shown only when the results differ ($P<0.05$). When the interactions between the clover and fertilizer treatments were significant, the differences are shown for each level of fertilizer. To test whether thrips pressure changed with nitrogen level, the regression coefficients were analysed using the level of nitrogen as the independent variable.

Results

Nitrogen

At week 4 and 8 after planting, nitrogen levels in the shaft of the leek were higher ($P=0.05$) in treatment N_2 than in N_1. At week 4, similar levels of nitrogen were found in the leaves but by week 8 more ($P=0.05$) nitrogen was found in the leaves of the plants in treatment N_2 than in N_1. Within both levels of fertiliser, no differences were found in the nitrogen concentration between the monocropped and the intercropped leeks. By 16 weeks after planting in both cropping systems, no differences were detected in the levels of leaf and shaft nitrogen in the plants analyzed from the plants in the N_1 and N_2 treatments (Table 1). Lower (P=0.05) levels of nitrogen were found in the shaft and leaves of the leeks in the non-fertilised monocropped plots than in the fertilised plots. However, the lowest concentrations were found in the non-fertilised intercropped plots. No clover/fertilizer interactions were recorded.

Thrips

At 4, 8 and 16 weeks after transplanting, more thrips were found in the monocropped than in the intercropped plots (Figure 1). At the higher nitrogen concentrations (N_1 and N_2), in both cropping systems, no differences (P>0,05) were detected in the thrips pressure (Table 2. - For brevity, only the results of week 16 are given). Within the range of the nitrogen concentrations measured in the shaft and the leaves, which varied between 1.4 and 4.4%, thrips numbers were similar. None of the regression coefficients differed significantly from zero (Table 2. - Only the results of 16 weeks after transplanting are given). There was no interaction between the presence of clover and the amounts of fertiliser applied. At the final assessment 16 weeks after planting, only one-fifth as many thrips were found on the intercropped as on the monocropped leek plants. (4429 ± 306 and 896 ± 319 thrips on the monocropped and intercropped leeks, respectively).

Table 1. Percentage N in the shaft and leaves of leek plants at 4, 8 and 16 weeks (Wk) after planting, following fertilization at 0, 50 and 150 kg N/ha (N_0, N_1 and N_2, respectively) of plots either with or without clover (+ and -, respectively).

	Shaft						Leaves					
	N_0		N_1		N_2		N_0		N_1		N_2	
Wk	+	-	+	-	+	-	+	-	+	-	+	-
4	-	-	1.52a	1.34a	1.74b	1.78b	-	-	2.80a	2.91a	3.16a	3.27a
8	-	-	4.15a	4.13a	4.64b	4.58b	-	-	2.62a	2.49a	3.00b	3.08b
16	1.44a	2.15b	3.30c	3.54c	3.62c	3.68c	2.06a	3.43b	4.10c	4.39c	4.35c	4.40c

Data tested using an ANOVA, with intercropping and N as factors. Different letters indicate significant differences within rows at P<0.05. There were no N and clover interactions.

Discussion

In this study, fewer onion thrips were found in the leek/strawberry-clover intercrop than in the leek monocrop. However, the numbers of thrips present were no correlated with either the percentage of nitrogen found in the plant foliage or in the leek shaft. The tendencies for more insects to be present on the high-nitrogen host plants (Minkenberg & Fredrix, 1989), and for there to be a positive relationship between tissue nitrogen levels and herbivore density, were not apparent in the interaction between onion thrips and leek. Within the range of nitrogen concentrations measured in the shaft and leaves, which fluctuated around the concentrations found normally in commercial leek crops (Booij *et al.*, 1993), the number of thrips found were similar.

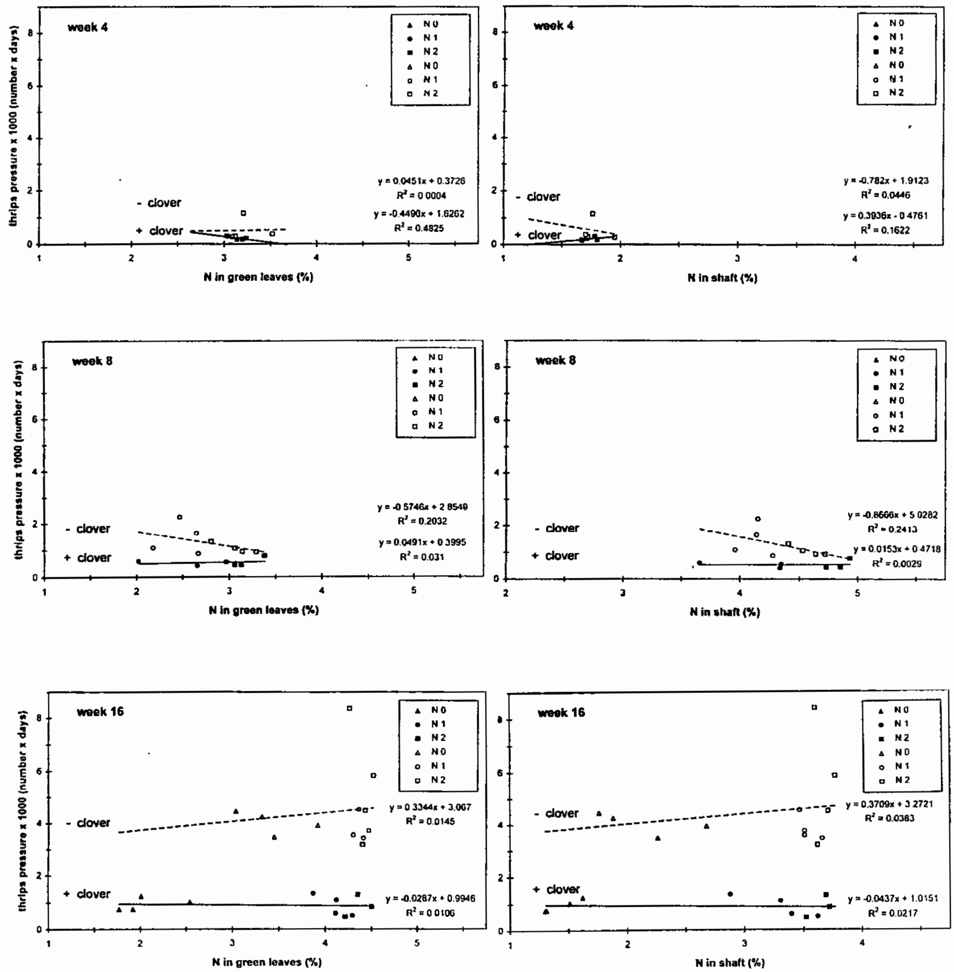

Figure 1. Thrips pressure (number x days) at 4, 8 and 16 weeks after transplanting in a leek monocrop and a leek/clover intercrop (- clover and + clover, respectively) with 0, 50 and 150 kg/ha N fertilization (N_0, N_1 and N_2, respectively). The percentage N in the green leaves or the shaft was used as the independent factors.

In the range of fertiliser doses tested (0, 50 and 150 kg/ha), the suppression of *T. tabaci* was similar in both the fertilised and non-fertilised intercrops. In contrast to other pest species, plant quality, as assessed by *T. tabaci*, appeared not to be related to nitrogen content. In the leeks intercropped with clover, the reductions in the numbers of thrips found were similar to those reported by Theunissen *et al.* (1995). In addition, the cosmetic damage (unpublished data) was much lower in the intercrop, even though the yield of leeks was similar in both the intercropped and the monocropped plots.

Table 2. ANOVA of the effects of clover (+, -) and N concentration, in the shaft (N_{shaft}) or leaves (N_{leaf}), on thrips pressure for week 16.

Source of variation	d.f.	s.s	F-value	P
+ clover	1	71623281	60.05	***
N_{shaft}	1	200339	0.17	NS
N_{shaft} x clover	1	68751	0.57	NS
residual	19	22660645		
total	22	95170017		
+ clover	1	71623281	58.63	***
N_{leaf}	1	25483	0.02	NS
N_{leaf} x clover	1	311129	0.25	NS
residual	19	23210124		
total	22	95170017		

where *** = P<0.001, NS = not significant

The factorial design of the experiment, which takes into account the relative effects of fertiliser and intercropping, is crucial for understanding the interplay between leek management practices and pest regulation.

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We thank C. Booij and J. A. Guldemond for comments on the manuscript and P. F. G. Vereijken for his help with the statistical analyses.

Résumé

Influence du semis de trèfle associé et de différents niveaux de fertilisation sur le thrips de l'oignon en culture de poireau

Le nombre de thrips de l'oignon trouvé en monoculture de poireau et dans l'association poireau / trèfle a été noté pour déterminer s'il y a une interaction entre la culture intercalaire et les quantités de fertilisation appliquées pour supprimer les populations de *Thrips tabaci* dans les cultures de poireau. Dans les deux systèmes de culture, l'azote minéral était apporté aux doses de 0, 50 et 150 kg/ha. Ainsi, il y avait une concentration d'azote beaucoup plus faible dans les feuilles vertes et le fut des poireaux dans les parcelles non fertilisées. Les densités de thrips furent plus basses dans les parcelles de culture intercalaire que dans les parcelles conduite en monoculture. Le nombre de thrips recensés n'est pas corrélé à la quantité d'azote présent dans le feuillage ou le fut des plants de poireau. A la différence de la réponse d 'autres espèces de ravageurs à l'amélioration de la qualité de la plante, *T. tabaci* ne semblent pas influencé par de tels échanges.

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Host-plant finding by insects – "appropriate/inappropriate landings" a mechanism based on the behaviour of pest insects of cruciferous crops

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Abstract: The critical mechanism that determines why fewer pest insects are found on host plants growing in diverse backgrounds is based on 'appropriate/inappropriate landings'. In this hypothesis, volatile chemicals emanating from host-plants indicate to flying insects that they are moving over suitable host plants. Insects that fly over such plants growing in bare soil will be stimulated to land on the only green objects available to them, host plants, and so most landings will be 'appropriate'. In contrast, insects flying over undersown crops will land in proportion to the relative areas occupied by the host and non-host plants, as pest species do not discriminate between host and non-host plants when both are green. Hence, many of these landings will be 'inappropriate'. The insects that land on the non-host plants will then fly off again, and depending on the distance flown before being stimulated again to land on another green object, could land eventually on a host-plant.

Key words: Undersowing, visual stimuli, diverse backgrounds, volatile stimuli

Introduction

Many researchers have shown that the numbers of pest insects found on cruciferous crop plants are reduced considerably when the background of the crop is allowed to become weedy (Dempster, 1969; Smith, 1969; Dempster & Coaker, 1974; Smith, 1976), when the crop is intercropped with another plant species (O'Donnell & Coaker, 1975; Tukahirwa & Coaker, 1982; Ryan *et al.*, 1980; Garcia & Altieri, 1992) or when the crop is undersown with a living mulch (Theunissen & Den Ouden, 198O; Theunissen *et al.*, 1994; Finch & Edmonds, 1994; Theunissen *et al.*, 1995).

This paper describes briefly certain shortcomings of the earlier hypotheses and champions the cause of a new hypothesis, based on "appropriate/inappropriate landings" (Finch, 1996), in which it is visual, rather than chemical, stimuli that are critical in determining where the insects actually land.

Earlier Hypotheses

In the five earlier hypotheses, it was suggested that diverse "backgrounds" reduced plant colonization by pest insects through 1) the undersown crop physically impeding the pest during host-plant finding (Perrin, 1977) (Figure 1 – Hypothesis 1); 2) visual camouflage in which the host plants become less "apparent" (Feeny, 1976) when presented amongst other green foliage (Smith, 1976) (Figure 1 – Hypothesis 2); 3) the volatile chemicals released by the undersown crop directly deterring the pest species (Uvah & Coaker, 1984) (Figure 1 – Hypothesis 3); 4) the odours of the host-plant being "masked" by those of the undersown crop (Tahvanainen & Root,

1972) (Figure 1 – Hypothesis 4); or through 5) root exudates from the clover altering chemically the physiology of the host-plant (Theunissen, 1994) (Figure 1 – Hypothesis 5).

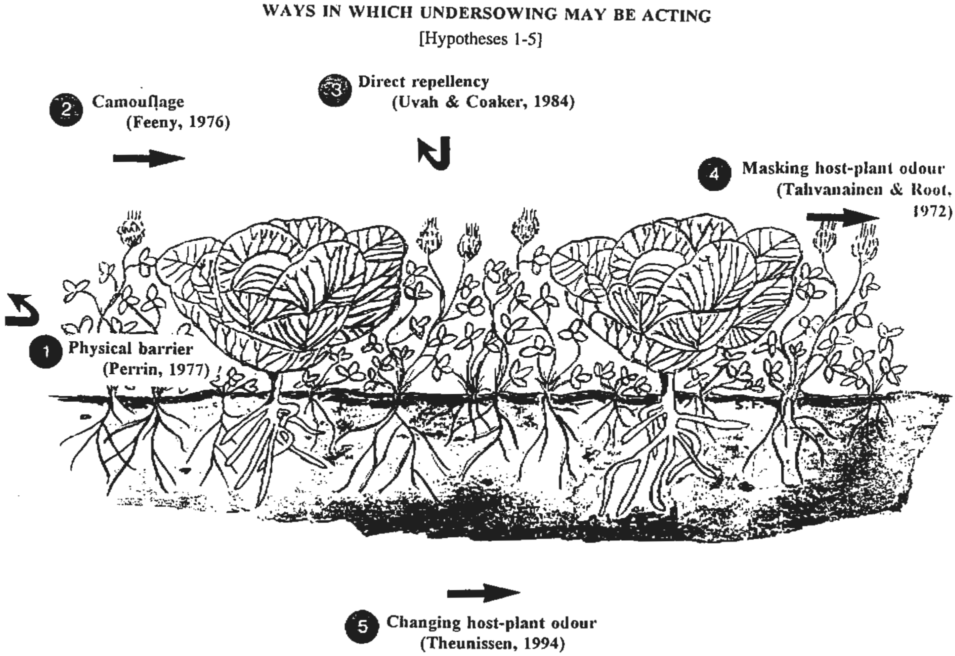

Figure 1. Schematic diagram of the way that undersowing may be acting, according to the five earlier hypotheses. The arrows indicate the response of the insects.

As can be seen from Figure 1, hypotheses 1 & 3 differ in that the insects are deterred directly by either physical (1) or chemical (3) stimuli, whereas the other three hypotheses, 2,4 & 5, are really all just "elegant variations" of the same theme.

Although four of the five underlying mechanisms behind these hypotheses were first suggested between 13-25 years ago, none of them have been substantiated experimentally (Finch & Kienegger, 1997). The first two mechanisms, physical interference (Perrin,1977) and visual camouflage (Smith, 1976) appear to be involved to some degree, but the other three do not. For example, as most of the plants used in the tests of Kienegger & Finch (1996) were left in their pots during the short experimental periods, the non-host plants could not possibly have caused physiological changes (Theunissen, 1994) in the host plants. Similarly, no experimental evidence has been produced to support Uvah & Coaker's (1984) suggestion that the non-host plants could produce their effect through direct chemical deterrence. The remaining possibility that the host-plant odour is being "masked" by that of the non-host plant (Tahvanainen & Root, 1972) also seems unlikely, as the same effect was produced when the host plants were surrounded with weeds (Dempster, 1969; Smith, 1976), with spurrey (*Spergula arvensis*) (Theunissen & Den Ouden, 1980) or with peas (*Pisum sativum*) (Kostal & Finch, 1994), all of which have different odour profiles, both from each other and from the clover. Furthermore, odours seem to be less important during this phase of host-plant finding, as similar results were produced when the host-plants were surrounded with non-odorous plant models (Kostal & Finch, 1994) or simple sheets of green paper (Ryan *et al.,* 1980; Kostal & Finch, 1994).

Hence. once the volatile chemicals characteristic of a host plant have stimulated the receptive insects to land, the choice of landing site is governed by visual, rather than chemical, stimuli.

New Hypothesis

The data published to date, indicate clearly that the differences in pest insect distributions resulting from undersowing do not occur as a result of either the Resource Concentration Hypothesis (Root, 1973) or the Enemies Hypothesis (Root, 1973), but are simply the cumulative effects of insects landing in different proportions on host plants and non-host plants during the initial phase of plant colonization (see Finch & Edmonds, 1994: Finch, 1996; Finch & Kienegger, 1997).

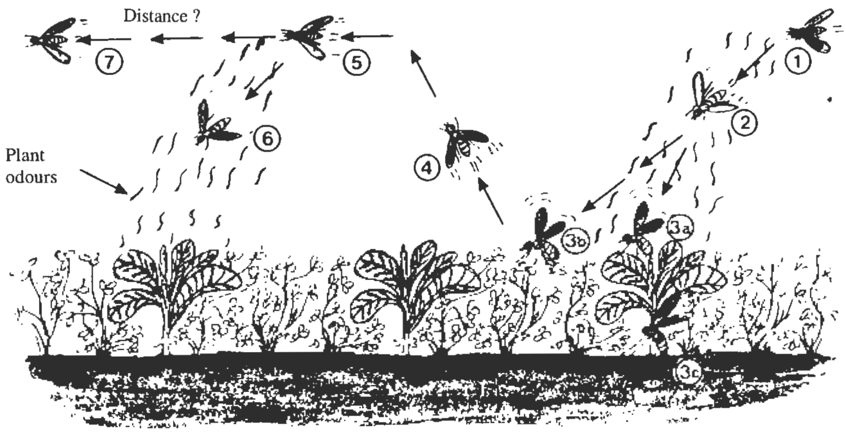

Figure 2. Schematic diagram to illustrate how diverse backgrounds, here represented by clover, influence host-plant finding by the cabbage root fly. Numbers = insect actions 1-7.

We feel that the mechanism governing why different numbers of pest insects are found on host plants growing in bare soil and in diverse backgrounds can be explained most clearly by the "appropriate/inappropriate landings" hypothesis proposed by Finch (1996). In this hypothesis, landing on host-plants consists of a series of actions in which volatile chemicals emanating from host-plants indicate to flying insects that they are moving over suitable host plants (Figure 2 – Action 1). Insects that fly over such plants growing in bare soil will be stimulated to land (Figure 2 – Action 2) on the only green objects available to them, host plants (Figure 2 – Action 3a), as they avoid landing on brown surfaces such as soil, and so most landings will be 'appropriate' and many of the insects will then lay (Figure 2 – Action 3c). In contrast, insects flying over undersown crops will land in proportion to the relative areas occupied by the host (Figure 2 – Action 3a) and non-host plants (Figure 2 – Action 3b), as pest species do not discriminate between host and non-host plants when both are green (Moericke, 1952; Prokopy *et al.*, 1983; Kostal & Finch, 1994) and so many of the landings (Figure 2 – Action 3b) will be 'inappropriate'. The insects that land on the non-host plants will then fly off again (Figure 2 – Action 4), and depending on the distance flown (Figure 2 – Action 5) before being stimulated again to land on a green surface (Figure 2 – Action 6), could land eventually on a host-plant. In both situations, however, the host-plant on which the insect first lands may itself not be sufficiently stimulating to arrest the pest insect and hence the overall process will then be repeated. Whether the insects that have made 'inappropriate landings' will remain in the locality will depend mainly upon whether the volatile stimuli released by the host plants are sufficiently stimulating to prevent the insects moving elsewhere (Figure 2 – Action 7).

Résumé

Recherche de la plante hôte par les insectes « atterrissage approprié/inapproprié » un mécanisme de base sur le comportement des ravageurs des cultures de crucifères.

Le mécanisme critique qui détermine pourquoi très peu d'insectes ravageurs sont trouvés sur les plantes hôtes croissant sur différents substrats est basé sur l'atterrissage approprié / inapproprié . Dans cette hypothèse, les composés chimiques volatiles provenant de la plante hôte indiquent aux les insectes en vol qu'ils se déplacent sur des plantes hôtes utilisables. Les insectes qui volent sur de telles plantes poussant sur sol nu seront stimulés pour atterrir seulement sur les objets verts utilisables pour eux, les plantes hôtes, et la plupart des atterrissages seront « appropriés ». Au contraire, les insectes volants sur une culture associée atterriront en proportion de la surface relative occupée par les plantes hôtes et non hôtes, puisque les ravageurs ne discriminent pas les plantes hôtes des non hôtes quand les deux sont vertes. Ainsi, beaucoup de ces atterrissages seront « inapropriés ». Les insectes qui atterrissent sur les plantes non hôtes voleront alors de nouveau, et en fonction de la distance de vol avant d'être à nouveau stimulé pour atterrir sur un objet vert, éventuellement sur une plante non hôte.

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The impact of different intercropping systems on herbivorous pest insects in plots of white cabbage

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Abstract: We tested the effects of different systems of intercropping on the population dynamics of pest insects in plots of white cabbage. Field experiments were done at Braunschweig and at Hannover in a randomised block design involving four treatments, each replicated six times. Two species of clover, strawberry clover (*Trifolium fragiferum*) and subterranean clover (*Trifolium subterraneum*) were used as intercrops. Other plots were mulched with barley straw and the "control" plots were left as bare soil. The undersown clover was drilled in rows at Braunschweig and as a full ground cover at Hannover. The abundance of most herbivores was reduced significantly when the cabbage plots were under-sown completely with clover. The clover sown in rows reduced the numbers of most pest species, but the reductions were not as pronounced as those from the complete cover. Straw mulching reduced the numbers of certain pest species but increased others. Only undersowing completely with clover reduced the infestation of the cabbage heads by the cabbage root fly (*Delia radicum*). The cabbage aphid (*Brevicoryne brassicae*) populations were reduced effectively by row undersowing, although the reductions were more pronounced in the full cover treatments. These reductions were due in part to a lower rate of colonisation by winged aphids. The effects of plant quality and predators on the population dynamics of the cabbage aphid remain obscure, but the numbers of syrphid larvae tended to be higher in the intercropped plots, despite there being lower numbers of aphids on the cabbage plants. Plant quality was much improved in the plots that contained clover. This helped to compensate for the reduced total plant weight from such plots when compared to the "control" plots.

Introduction

Commercial field vegetable growers are now faced with contrasting problems. On the one hand, market demands for high quality produce are putting considerable pressures on growers, on the other hand, consumers are increasingly sensitive to side effects arising from the use of pesticides in food production. In addition, environmental legislature is becoming stricter. This situation increases the interest in alternative methods of pest control. Undersowing a vegetable crop with plants, which are not related to the crop, reduces attacks by pest insects (Andow 1991) and may therefore be suitable for lowering pest damage. However, intercropping will only be accepted as a method if it works in a practical situation (Theunissen 1997). Consequently the mechanisms of pest reductions by intercropping have to be understood in detail if integrated pest management strategies are to include this method.

Two hypotheses have been put forward by Root (1973) to explain reduced pest populations in intercropped cultures: The "resource-concentration-hypothesis" assumes that the intercrop interferes with the ability of the herbivores to locate their host-plant, due to mechanical barriers, odour of the intercrop, or related factors. This results in a reduced pest colonisation of intercropped plants. In contrast, the "enemies-hypothesis" assumes that the intercrop and/or non-pest organisms living on such plants provide additional food sources for natural enemies. The resulting higher numbers of natural enemies in intercropped vegetables over time will ultimately produce enhanced control of herbivores on the crop plants. However, neither the influence of the intercrop on host-plant location, nor the role of natural enemies, have been tested rigorously enough in field experiments to separate these two mechanisms for different herbivore-intercrop combinations. To obtain more information on what was occurring under field conditions, we used white cabbage to test the influence of different clover species, or a straw mulch, on the population dynamics of the main pest species.

Material and methods

Field experiments were done at two different localities, a rural area near Braunschweig and a suburban area in Hannover. We used a randomised block design with four treatments, each replicated six times to test how two different low growing species of clover, and a straw mulch, affected pest infestations compared to those found on cabbage plants grown in bare soil. The clovers were strawberry clover (*Trifolium fragiferum*) and subterranean clover (*Trifolium subterraneum*). At Braunschweig, the clovers were undersown in one row between the rows of the crop plants (white cabbage, *Brassica oleracea* var. *capitata* cg. Minicole). At Hannover, each plot was sown with the same amount of clover in full cover. The cabbage plants were transplanted into the clover four weeks later. Straw mulching was done with barley straw obtained from the same origin for both areas. Pest insects and their natural enemies were counted visually twice a week on 48 to 72 plants per treatment. Head damage by *Thrips tabaci* and *Delia radicum* was assessed separately at harvest. Fertiliser and irrigation was applied when necessary. No insecticides were applied, even in the "control" plots.

Results and discussion

Undersowing of white cabbage with clovers reduced the numbers of many, though not all, pest species (Table 1). Different clover species resulted in nearly the same effects on the herbivorous species, but the full clover cover caused greater reductions in the numbers of *Brevicoryne brassicae, Thrips tabaci, Delia radicum* and *Phyllotreta* ssp., than either row intercropping or straw mulching. This result was due probably to the more complete ground cover. The increase in population numbers of *Thrips tabaci, Delia radicum* and *Phyllotreta* ssp., in the straw mulch may be explained in part by the different microclimatic conditions in the straw-mulched plots. In these plots, temperatures tended to be higher and humidity lower than in the clover-intercropped plots (Lehmhus, personal observation).

Although, all treatments resulted in reductions of several pest insects on the cabbage plants compared to the control, it was obvious that the different pest species were affected by to the intercropping treatments in species-specific ways. This was especially true for the lepidopteran pest species, as none of the intercropping treatments tested had any effect on their egg laying behaviour. Because lepidoptera adults are highly mobile, the resource concentration hypothesis might not go far enough to cover these species (Grez & Gonzalez 1995). In contrast, the polyphagous *Autographa gamma* benefited from one intercrop treatment (*T. subterraneum*), as the first instar larvae preferred initially to feed on the clover and moved only later onto the cabbage. Therefore lepidopterous pests could cause problems in intercropping systems if they occurred in numbers higher than recorded in the current experiment.

Table 1. Influence of different intercropping systems on the population dynamics of important cabbage pests in 1996; ⇑ = increased numbers compared to control, ↓ = reduced numbers compared to control, 0 = no differences compared to control, *T. subterraneum* = subterranean clover, *T. fragiferum* = strawberry clover. Two arrows indicate that the differences between the intercrop and the control treatments were large.

	Hanover full cover			Braunschweig row intercrop		
	Straw mulch	*T. subt.*	*T. frag.*	Straw mulch	*T. subt.*	*T. frag.*
Brevicoryne brassicae	↓	↓↓	↓↓	↓	↓	↓
Thrips tabaci	⇧	↓	↓	⇧	↓	↓
Plutella xylostella	0	0	0	0	0	0
Autographa gamma	0	⇧	0	0	⇧	0
Delia radicum						
a) Roots	⇧⇧	↓	↓	⇧⇧	↓	⇧
b) Head	↓	↓↓	↓↓	0	0	0
Phyllotreta atra + undulata	⇧	↓	↓	0	0	0

In 1996, the two most important pest species were the cabbage aphid, *Brevicoryne brassicae,* and the cabbage root fly, *Delia radicum.* The populations of the cabbage aphid were affected considerably by the different treatments. All treatments reduced the infestation of cabbage aphid when compared to the control plots, but the reductions were highest in the clover treatments with full cover. As the host plants were colonised initially by alatae aphids, differences in numbers of alatae between the treatments could explain the observed differences in aphid populations. The colonisation of the cabbage plants by alatae aphids was reduced significantly in the undersown plots (Figure 1). The more soil covered with clover (Hannover compared to Braunschweig), the fewer alatae found on the cabbage plants.

Locating the host plant should become less easy for flying insects when the soil is covered by non-host plants. Straw mulch, with a contrasting colour compared to the cabbage plants, had only a marginal effect on the rate of colonisation by the aphids. These results could be explained by the in-flight orientation of aphids. The alatae use visual cues to locate their host plants; it is thus more likely that they accumulate on the more easily detectable cabbage plants in the control or straw mulch plots (Costello & Altieri 1995, Vidal 1997). We postulate that colonisation over time is the crucial factor for aphids in intercrops, but that other factors could play a role after colonisation has occurred.

Natural enemies are regarded as an important factor in the population dynamics of aphids. The common parasitoid of the cabbage aphids in our experiments, *Diaretiella rapae*, appeared only late in the season and was more numerous in the control plots. Thus, it could not be responsible for the lower aphid densities on intercropped plants. Syrphids, predominantly *Episyrphus balteatus*, were the most common aphid predators on the cabbage plants, but eggs or larvae could not be found in considerable numbers until the aphid densities reached pest status in the control plots. However, in all four treatments, linear regressions of hover fly eggs, larvae and pupae against aphid densities on the cabbage plants explained most

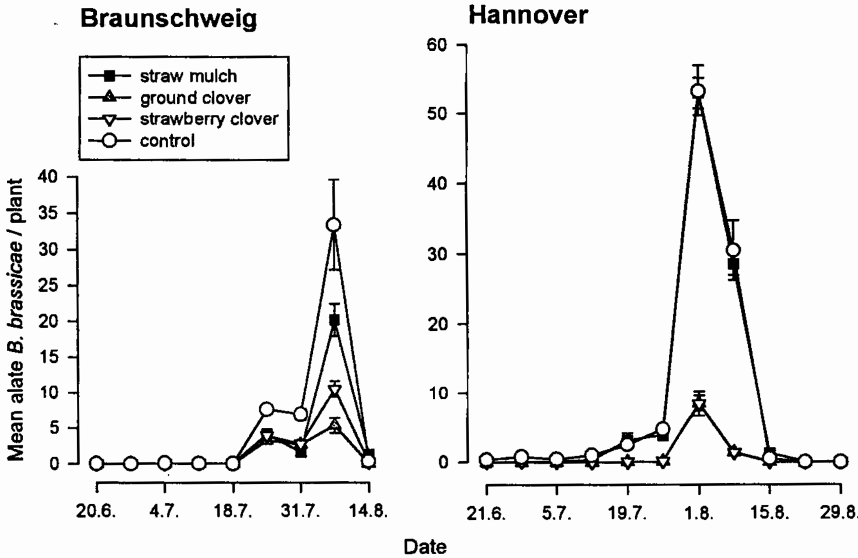

Figure 1. Numbers of alate *Brevicoryne brassicae* (means±SE) recorded at Braunschweig (row intercrop) and Hannover (full cover intercrop) in the four treatments (RMANOVA, Braunschweig: n = 288; F – 20,1; p<0,001; Hannover: n = 336; F = 161,5; p<0,001).

of variance found (Figure 2). Despite lower aphid numbers in intercropped and mulched plots, syrphid numbers were slightly higher, or at least as high, in these treatments compared to the control plots. Consequently the predator-prey ratio was enhanced in intercropped and mulched plots compared to the controls. Similar results have previously been reported (Smith 1976, Vidal 1998). However, although the slopes of the regression lines do differ significantly between the clover intercrops and the controls, this still does not answer the question if, and to what extent, the syrphids influenced the numbers of aphids. We still need properly designed experiments to unravel the numerical and functional responses of predators in intercropped systems. For the cabbage root fly, *Delia radicum,* natural enemies did not play an important role. Only the parasitoid *Trybliographa rapae* was found in very low numbers. In this case the enemies hypothesis has to be rejected.

Two different kinds of infestation by *D. radicum* are recorded in the northern parts of Germany. During the whole season, the flies lay eggs in the soil near the plant stem and the subsequent larvae mine into the roots of the plants. However, later in the season, when the heads of the cabbage begin to form, eggs are also laid on the base of head leaves and larvae then mine into the cabbage heads. Such infestations cause a high loss in crop quality and this is a severe problem for farmers in this part of Germany.

The numbers of cabbage fly eggs laid in the soil were reduced considerably by intercropping with clovers. These effects were more pronounced in full cover than in row intercropping. Thus, according to Hofsvang 1991 and Theunissen & Schelling 1992 the clovers could be acting as a mechanical and olfactory barrier that disturbs the egg-laying behaviour of the fly. In contrast to earlier results (Hellqvist 1996), mulching with barley straw increased the number of eggs laid in the soil. The reasons for these contrasting results are not clear.

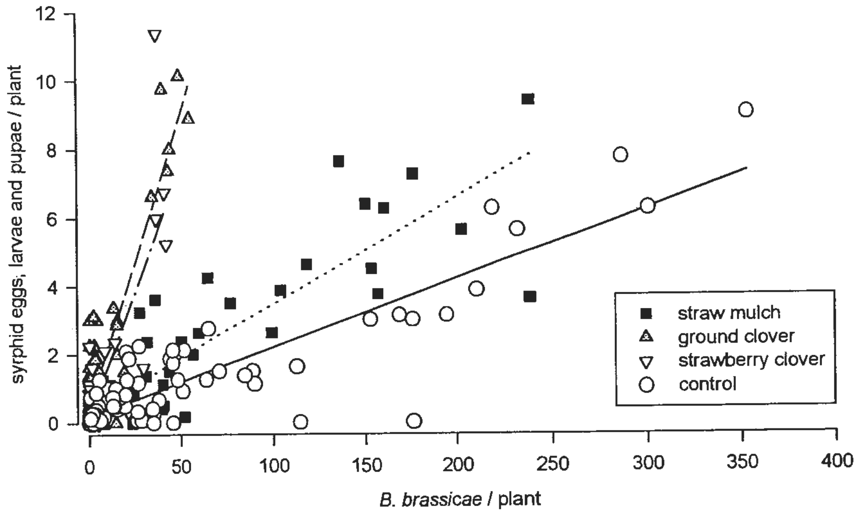

Figure 2. Linear regressions of the number of *Brevicoryne brassicae* and syrphid numbers (sum of eggs, larvae and pupae, with *Episyrphus balteatus* being the dominant species in Hannover) recorded on the cabbage plants; straw mulch, $y = 0,35 + 0,03x$, $r^2 = 0,78$; ground clover, $y = 0,49 + 0,17x$, $r^2 = 0,84$; strawberry clover, $y = 0,19 + 0,14x$, $r^2 = 0,66$; control, $y = 0,18 + 0,02x$, $r^2 = 0,78$.

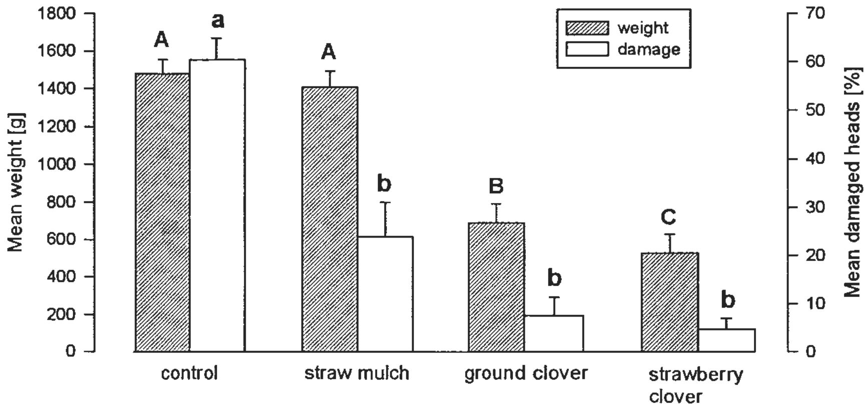

Figure 3. Mean number of cabbage heads damaged by *D. radicum* and the mean head weight (means±SE) in the four treatments tested in Hannover (full cover intercrop); Tukey-Test for damaged heads: n = 384; F – 29,0; p<0,001; for head weight: n = 384; F = 160,5; p<0,001).

No differences in the rate of infestation of cabbage heads by the cabbage root fly were found using the row intercrop at Braunschweig. However, in Hannover, where both species of clover were sown as full covers, head infestations were reduced to a considerable extent. Moreover, straw mulching also reduced head infestation, but not to the same extent. No correlation was found between head size and damage. The results suggest that ground cover of the intercrop has a crucial role here (Coaker 1980), but other factors may also be involved.

Despite lower pest populations compared to row intercrops, full cover intercrops might not be the best practical solution for growers. Compared to row intercropping, these treatments resulted in severe competition between the clover and the cabbage crop and reduced the cabbage yield by up to 50%. Such yield reductions were not observed in row intercropping or straw mulching.

The results of this study do not give a simple solution for the explanation of the effects of intercropping on different pest insects on cabbage. However, it seems likely that in those species responding to intercropping regimes the mechanisms proposed by the resource concentration hypothesis are more important and that the enemies hypothesis might only play a minor role in these cases.

Résumé

L'impact de différents systèmes de cultures intercalaires sur les ravageurs phytophages dans des parcelles de chou blanc

Nous étudions les effets de différents systèmes de cultures intercalaires sur les dynamiques de population des ravageurs en parcelles de chou blanc. Les parcelles d'expérimentation ont été mises en place à Braunschweig et à Hanovre en blocs randomisés, comprenant quatre traitements, chaque condition est répétée six fois. Deux espèces de trèfle, le trèfle porte fraise (*Trifolium fragiferum*) et le trèfle souterrain (*T. subterraneum*) servent de plantes intercalaires. D'autres parcelles sont couvertes de paille d'avoine en mulch et les parcelles témoins sont maintenues en sol nu. Le trèfle est semé en rang à Braunschweig et à la volée à Hanovre. L'abondance de la plupart des phytophages était réduite de façon significative quand les parcelles de choux étaient entièrement couvertes par du trèfle. Le semis en ligne réduit le nombre de la plupart des ravageurs, mais la réduction n'était pas aussi prononcée que dans le semis à la volée. Le mulch réduit le nombre de certain ravageurs mais d'autres sont en augmentation. Seul le semis à la volée réduit les infestations de la mouche du chou (*Delia radicum*). Les populations de puceron cendré du chou (*Brevicoryne brassicae*) sont réduites efficacement dans le semis en ligne et de manière plus prononcée dans le semis à la volée. Ces réductions sont le résultat en partie d'une infestation plus faible des puçerons ailés. Les effets de la qualité des plantes et le rôle des prédateurs sur la population du puceron cendré reste difficile à interpréter, mais le nombre des larves de syrphes tendait à être plus élevé dans les parcelles en intercalaire en dépit du fait que le nombre des pucerons était plus faible sur les choux. La qualité des plantes était bien améliorée dans les parcelles contenant du trèfle. Cette amélioration compense la réduction du poids total des plantes dans ces parcelles par rapport aux parcelles « témoins ».

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Host-plant finding and colonization by *Thrips tabaci* in monocropped leeks and in leeks undersown with clover

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Abstract: A field experiment was carried out using leek (*Allium porrum*) plots without undersowing (monocropped leek) and rings of leek plots undersown with clover to obtain information on host-plant finding and colonization by *Thrips tabaci*. The first infestation by the adult thrips occurred simultaneously in both the monocropped and the intercropped plots. Within a few days of infestation, the adult populations in the two treatments started to differ. The populations of thrips larvae, which were dependent on adult migration, feeding and oviposition, soon started to differ between the monocropped and the intercropped plots. The monocropped plots were not the source of adult thrips, as both adult and larval populations in the intercropped leeks seemed to be limited by changed host plant quality which resulted in induced resistance. The quantity and quality of the crop harvested from both types of plot are discussed.

Key words: Undersowing, *Allium porrum, Thrips tabaci, Trifolium subterraneum*

Introduction

Despite the difficulties of effectively controlling thrips (*Thrips tabaci* Lindeman), in crops of the important field vegetable leek (*Allium porrum* L.), only limited research has been done to produce acceptable alternative methods of control. In commercial situations, insecticidal control, using many different insecticides, is perceived as the only way of controlling thrips infestations. However, time and again, insecticide treatments have failed because the local thrips populations have developed resistance to the insecticide applied. Failure to obtain acceptable control starts the familiar sequence in which the dosage and frequency of treatments is increased until the pest becomes totally resistant. Occasionally, newly registered compounds buy a few more years until the cycle of events starts all over again.

Attempts to find non-chemical methods for controlling thrips in leek have been made both in Switzerland (Müller-Schärer, 1996) and the Netherlands (Theunissen & Schelling, 1993). Undersowing leek crops with clover reduced both adult and larval populations of *Thrips tabaci* (Theunissen & Schelling, 1996, 1997, 1998). However, the mechanisms behind this reduction in pest numbers remain obscure. In an experiment with a point source of monocropped leek plots surrounded by plots undersown with clover we tried to obtain more information on the behaviour of the thrips during crop colonization and population development.

Materials and methods

The experiment was carried out in a field (110 m x 115 m) in which the soil was sandy. At the centre of this field, nine square (56.25 $m^{2)}$ plots were laid out (Figure 1). The central plot was left fallow and the other eight were used alternately as the monocrops plots and the plots undersown with clover, *Trifolium subterraneum* L. cv. Trikkala. Only undersown plots were used in two outer rings (Figure 1). These plots were sited 30 m and 67.5 m, respectively, from the inner ring. The distances were chosen arbitrarily, to get a good spread of the plots through the experimental field. Grass was sown between the leek plots. The plots were positioned in such a way that one axis was in a Southwest-Northeast direction, the prevailing wind direction in the Netherlands.

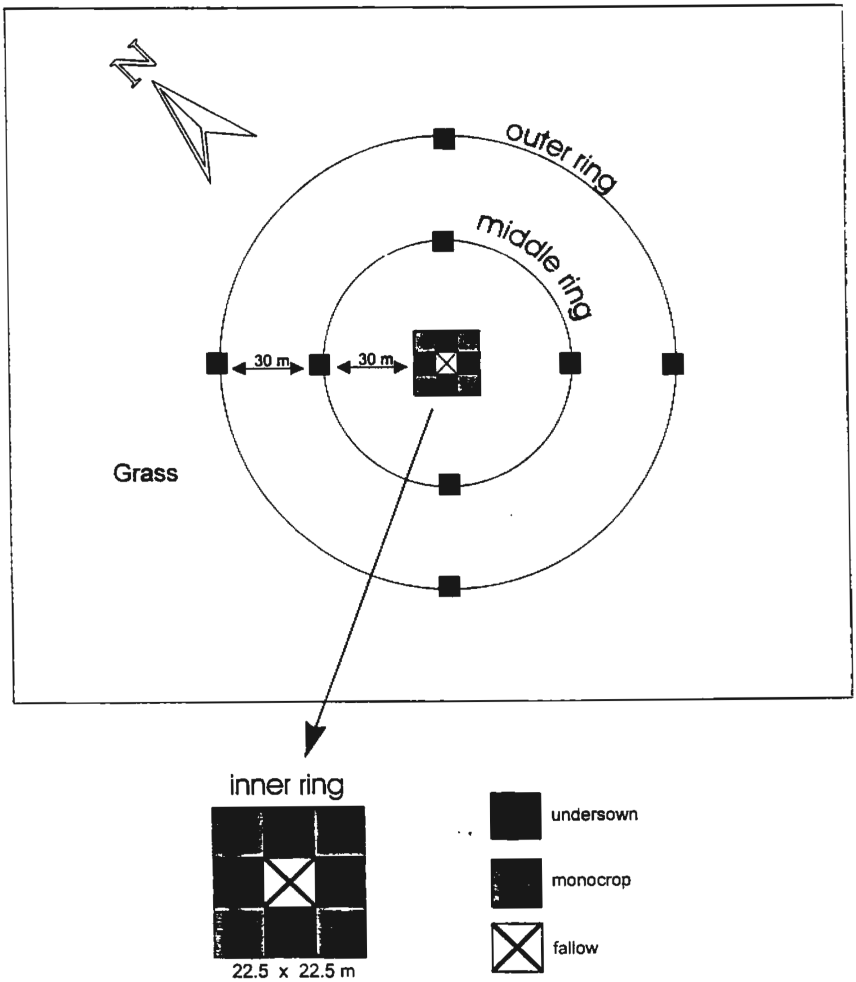

Figure 1. Lay-out of the experiment. In the centre, the inner ring consists of alternating monocropped and undersown plots of leek. The middle and outer rings contain only undersown plots of leek. Grass was sown in the area between the plots.

The clover was sown on 12 April 1996. The leeks, cv. Albana, were planted on 14 June after the clover had been mown. About 50% of the soil surface was covered with clover (range 40-60%). The leeks were spaced 55 cm between the rows and 15 cm within the rows. Each plot contained 14 rows each with 50 leek plants. The total number of leeks in the experiment was 11,200. The clover was mowed when necessary (> 15 cm high). Prior to planting, the leek plants were checked for thrips and rust infestation as a quality control of the planting material. All plots received the same amount of fertilizer, given in 3 doses: 120 kg/ha NPK at planting and 75 kg/ha KAS at both 6 and 12 weeks after planting. No pesticides were used in this experiment.

The layout of the experiment was based on the assumption that equal numbers of adult thrips would pass over each part of the field during the crop infestation period. We had no reason to suppose otherwise.

Following planting, the plots were inspected twice a week for the first 6 weeks after which they were inspected once a week. Five plants were taken at random from each plot. Records were taken from each individual plant of the diameter of the shaft, the symptoms of thrips feeding, signs of leek moth (*Acrolepiopsis assectella* Zeller) feeding and the presence of rust (*Puccinia allii* Rudolph). The number of thrips adults and larvae present were counted leaf by leaf. Infection by rust and infestation by leek moth were low and did not affect the outcome of the experiment.

Symptoms of damage were expressed in the classes described earlier (Theunissen & Schelling, 1996). To be marketable, the plants should have a value below 2. A value between 0-1 indicates that the quality of the leeks is first class.

During the cropping period, the growth of the crop was monitored from the diameter of the sampled plants. This diameter can be translated into harvestable yield. When the monocropped plants were ready for harvest, 25 plants were taken from each of the plots of the inner ring, weighed individually, and assessed for quality according to the criteria described earlier (Theunissen & Schelling, 1996). The leeks were harvested on 15 October 1996.

The data on population development were tested by a Friedman 2-way ANOVA for both replicate and treatment effects. The mean number of thrips/plant and the standard error were determined for each sampling date. Another way to describe the population pressure of the thrips on the crop was to determine the cumulative thrips pressure over time, using the formula:

$$\Sigma(N_1+N_2)/2*dt,$$

where N_1 and N_2 are the mean population size/plant at time t_1 and t_2 and dt is the difference in days between the observation moments t_1 and t_2, expressed in Julian days.

Yield data were analyzed for block and treatment effects by ANOVA. Differences between mean weight of the harvested plants and mean level of symptoms were tested using least significant differences (LSD's).

Results

First adult thrips were found in both the monocropped and the undersown plots 12 days after planting. The numbers of adults in such samples were very low, and averaged about one thrip/5 plants. In the monocropped leek plots the numbers of adults continued to rise slowly, while those in the undersown plots remained at a very low level (Table 1). At this stage the low levels of thrips adults and the small samples could provide no more than an indication of

Table 1. The numbers of adult *T. tabaci* population recorded in monocropped and undersown plots of leek. Mean number of adults/plant and the standard error of the mean are given per date during the first six weeks after planting. Each mean represents 20 plants.

Date of sample		Inner ring monocrop		Inner ring undersown		Middle ring undersown		Outer ring undersown	
		mean	se	mean	se	mean	se	mean	se
June	14	0	0	0	0	0	0	0	0
	26	0.1	0.05	0.05	0.05	0	0	0.07	0.05
July	2	0.55	0.22	0.1	0.05	0	0	0.13	0.1
	5	0.3	0.058	0	0	0	0	0.07	0.05
	9	0.6	0.18	0	0	0.07	0.05	0	0
	12	0.6	0.28	0.05	0.05	0.07	0.05	0	0
	16	0.95	0.096	0.2	0.11	0.07	0.05	0.07	0.05
	23	0.45	0.2	0.2	0.08	0.07	0.05	0.13	0.09
	26	0.95	0.96	0.1	0.1	0.2	0	0.47	0.17
	30	2.15	0.63	0.3	0.19	0.53	0.31	0.27	0.19

the possible infestation. A great deal of variability was expected, and found, at this stage. Therefore, the findings during the first observations cannot be analyzed.

Adult population development and the corresponding accumulated adult thrips pressure on the crop are shown in Figure 2. After the initial phase of crop infestation, the level of adult thrips populations in the monocropped plots differed significantly ($P<0.05$) from those in the undersown plots. However, differences were not found between the replicates of the undersown plots, nor was there any effect of the alignment of plots according to the prevailing wind direction. Linear regression of the accumulated adult pressure over time gave the following parameters:

	intercept	regression coefficient	r^2
monocrop, inner ring	-74.9	0.41	0.940
intercrop, inner ring	-30.1	0.16	0.902
intercrop, middle ring	-32.1	0.17	0.900
intercrop, outer ring	-24.1	0.13	0.902

The first larvae were found in the monocropped plots 18 days after planting, 6 days after the first adults were recorded. In the undersown plots the larvae in the inner ring were found 25 days after planting, approximately 7 days later than in the monocropped plots. During the first 6 weeks after planting, the population of larvae in the intercropped plots remained low (<1 larvae/plant). The development of larval populations and their pressure on the crop is shown in Figure 3. The best fit for the accumulated larval pressure on the crops is $y^{0.5} = a+bx$, which results in the following parameters:

	intercept	regression coefficient	r^2
monocrop, inner ring	-65.0	0.35	0.969
intercrop, inner ring	-28.5	0.15	0.940
intercrop, middle ring	-29.0	0.15	0.937
intercrop, outer ring	-30.9	0.16	0.935

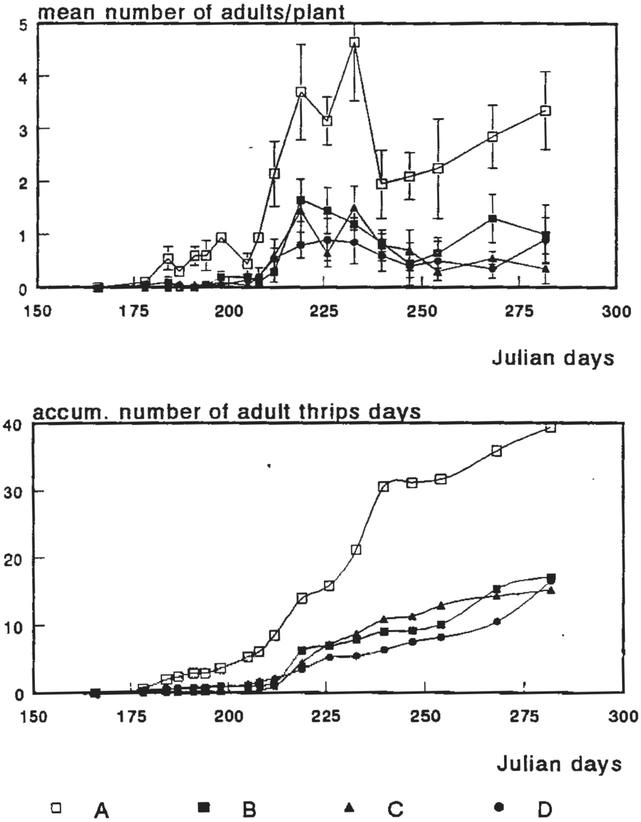

Figure 2. Top: Mean (±se) numbers of adult thrips sampled on each observation date, expressed in Julian days. Each data point is the mean from 20 plants. Bottom: The same population curves, expressed as accumulated thrips days, to indicate the adult thrips pressure on the crop. Symbols: A = monocroppped leeks, inner ring; B = undersown leeks, inner ring; C = undersown leeks, middle ring; D = undersown leeks, outer ring.

The variability in the numbers of larval and adult thrips/plant could be large. Recording extremely low or high values for a particular, situation can change radically the expected outcome. But this is common to all biological research. This variability is reflected to some extent in Figures 2 and 3.

During the cropping period, both the level of symptoms and the growth of the plants were monitored, to obtain "real-time" information on the quality and quantity of the crop during production (Figure 4). Because of the close proximity of the treatments, it was decided to harvest the plots from the inner ring. As usual, the crop plants growing in the clover had a slower rate of growth. This causes a problem when comparing yields. For example, when the monocrop is ready for harvest, the plants in the undersown plots are still growing and not yet at the harvestable stage. To compare both treatments, both sets of plants have to be harvested

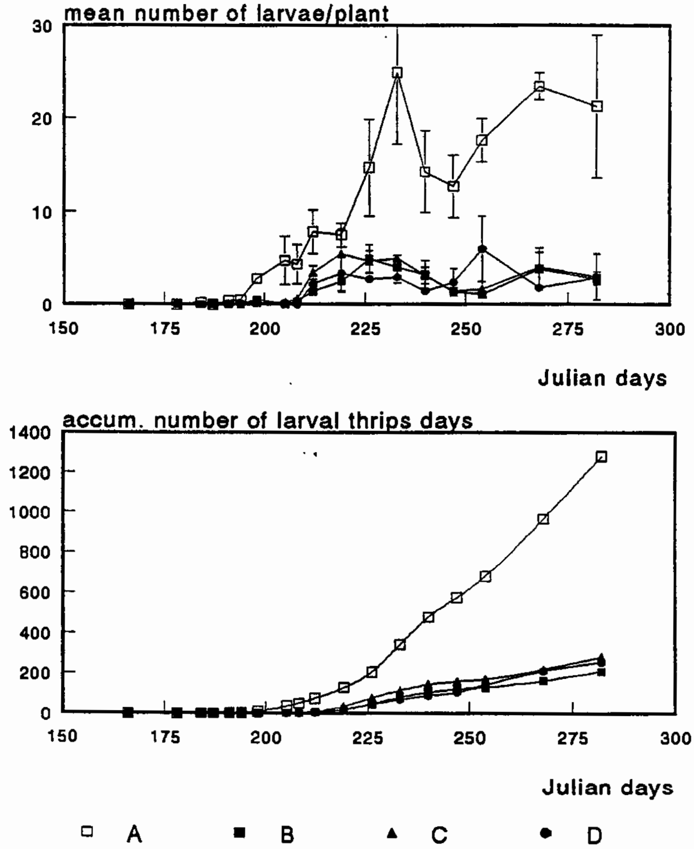

Figure 3. The same as Figure 2, but for the larval populations. Symbols: see Figure 2.

at the same time. This automatically reduces the yield from the undersown plots. When such plants were allowed to reach maturity a few weeks later, the difference in yield with the monocrop was eliminated. The mean weight per plant was 304 g (monocropped) and 286 g (undersown). This difference was not significant. The Land Equivalent Ratio (Mead & Willey, 1980) for the harvested product was 0.89 and for the marketable product 3.35, meaning that the harvested weight in the monocrop was larger but that the marketable part of the total monocrop harvest was much smaller. The quality of the undersown leeks was much better (mean symptoms 0.39 versus 2.56 for monocropped leeks).

The level of damage symptoms in the monocropped fields soon reached unacceptable levels (>2) as the thrips population increased, whereas the plants in the undersown fields showed less damage symptoms as they supported fewer thrips. At the time thrips numbers began to approach the threshold level (Theunissen & Schelling, 1997) the symptoms of crop damage rose. Decreasing thrips populations resulted in an improved symptom expression over time (Figure 4).

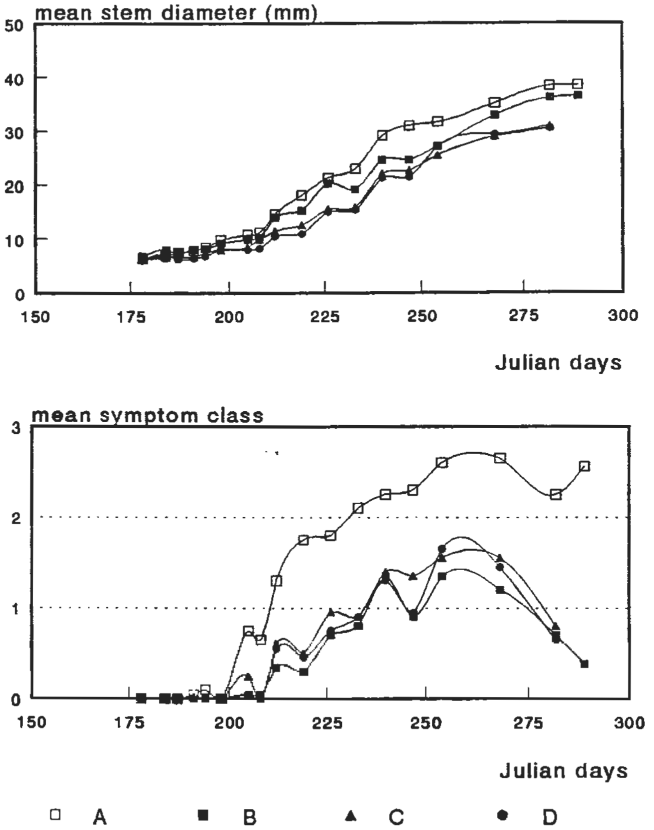

Figure 4. Top: Mean stem diameter (mm) of the sampled leek plants in the various treatments at each sample date (Julian days). The diameter of the harvested plants of the inner ring is added for day 289. Bottom: Means of values of the symptom class for thrips feeding on 20 the individual plants/sample date, including plants harvested from the inner ring. Symbols: see Figure 2.

Discussion

The first phase of crop colonization is *host plant finding* (Theunissen, 1997). In the context of the thrips-leek system, using monocropped and clover undersown leek plots, the first question is: do thrips adults distinguish between monocropped and undersown fields while still in flight? If there are any preferences for a particular treatment, the early infestation of the crop by adults would be expected to be different. We found the first adults both in the monocropped and in the undersown plots of leeks at about the same time and in the same, low numbers. Similar findings were recorded from experiments done during the previous five years (Theunissen & Schelling, 1996; 1998; - unpublished data). In most cases the first adults were found at the same time in both treatments. However, sometimes the first adults were found in the monocrop and in other years in the intercrop. Due to the limited discriminating power of the sampling method used at these low pest densities, statistical differences between the early infestation within the monocrop and intercrop plots could not be established. In this experiment, from day 184 to day 205, the crop infestation period, there was a trend that suggested the populations in the monocrops were higher. This might be caused by the mechanism of "appropriate/inappropriate landings" on host plant/undersown crop, respectively (Finch, 1996). These data lead us to conclude that there is some evidence that adults of *T. tabaci* show a pre-alightment "in-flight" orientation and selection for monocropped over undersown leek fields. The distance over which they are capable of distinguishing differences during this pre-alightment situation still needs to be determined. For the sake of clarity, it may help to distinguish between relatively long-distance pre-alightment flight behaviour (from crop to crop) and short-distance post-alightment flight behaviour (from plant to plant). There might be a difference between the two types of flight behaviour, triggered by physical contracts between the insect and the host plant.

The second phase of crop colonization is the *acceptance of the host plants*. Here, the question is: do thrips adults distinguish between monocropped and undersown leeks once they have landed in the plots? While we found the first adults in low numbers in both treatments, it was apparent that within days differences could be found between adult thrips populations in the monocropped and undersown leek plots. This was supported by earlier experiments (Theunissen & Schelling, 1996). This trend was easier to observe than to interpret. The feeding behaviour of thrips on monocropped and undersown leeks was studied using the EPG-technique (Harrewijn et al., 1996). While thrips adults continued to feed normally on monocropped leeks, they stopped feeding after 24 hours on leeks growing in clover (Harrewijn, pers. comm.). These observations support the hypothesis that, in the case of leek, changes in host-plant quality may be an important mechanism to explain thrips suppression (Theunissen, 1994). The disruption of feeding behaviour has important consequences for the success of reproduction and may influence the migration of the adult thrips. When undersown host plants are rejected by immigrating adults, the thrips may leave the crop. Immigrating gravid females may lay eggs and depart. The resulting larvae face the unsuitable host plant and mortality will be high. This scenario would explain the data on thrips population development we found consistently in these (Figures 2 and 3) and previous (Theunissen & Schelling, 1996) field experiments involving leek plants undersown with clover. Contacts with the host plant appear to produce different degrees of acceptance by adults that immigrate into monocropped and undersown leek plots. We interpret adult population development in both situations as the resulting equilibrium of immigration and emigration. This interpretation is supported by the fact that during the cropping season the curves in the intercropped fields follow those in the monocrops (Figure 2, top). When adults are abundant in and over the (mono)crops, inevitably more will land in the adjacent intercrops and the equilibrium will reach a new value. More eggs will be deposited in the undersown leeks and the course of larval populations in the undersown leeks will follow roughly that in the corresponding monocrops (Figure 3, top; Theunissen & Schelling, 1996). When log transformed accumulated numbers of adults/plant in monocrops and intercrops were compared over time, the regression lines had the same slope (regression coëfficient 0.016, $r^2 = 0.896$ monocrop; 0.017, $r^2 = 0.856$ inner ring intercrop) but different intercepts. This indicates that there were similar reactions from the prevailing conditions but that they were at different magnitudes for the two treatments.

Unsprayed monocropped leek fields are likely to produce high thrips populations during certain seasons. Whether such crops act as a source of adults for nearby undersown fields remains unanswered. If the monocrops in the current inner ring functioned as a point source of emigrating adults, it might be expected that the adult thrips populations in the undersown crops within the inner ring would be higher than those in the middle and outer rings. At low adult population levels, no differences were found between the various undersown plots. When the numbers of adults started to rise in the monocropped leeks, a slight trend towards higher adult populations might be found in the undersown plots within the inner ring (Figure 2), but these differences were not significant from the data from the other undersown plots. Therefore, we have no evidence that the monocrops act as a point source of adults for the undersown crops. If the equilibrium of immigration/emigration establishes itself very quickly, the effects of increased immigration could soon be nullified by increased emigration. Over the scale used in this experiment, there is no gradient in adult infestation from the inner to the outer ring. A question that remains to be answered is to what extent do monocrops function as "trap crops" and prevent the adults from moving to the less-favoured undersown crops. The local immigration/emigration pattern could be influenced by such a spatial distribution. There is also the question of what factors induce adult thrips to leave suitable host plants? Do they leave when the adult thrips population exceeds a certain threshold or due to a change in day length? On individual, unsprayed monocropped leek plants, populations of adult thrips range from a few to about 50 during the peak periods of infestation. If population density triggers adult emigration, is 50 adults the limit? In that case the field would contribute little to the local airborne thrips population. If the trigger density was considerably lower, why do we find these high densities? In our data we find high adult infestations between days 219 and 233. This is 47-61 days later than the longest day 21 June (day 172). The Julian days 111-125 (end of April-beginning of May) show the same day length before the beginning of summer. At about that time, adult thrips migrate from their winter to their summer hosts. It could be possible that a particular range of day lengths induces thrips to migrate.

Despite the slower growth of the leek plants undersown with clover, the plants produced were of a higher quality than those from the monocropped plots. This is the usual situation when pesticides are not applied (Theunissen & Schelling, 1996, 1997). For the grower, it is important to ensure that leeks of sufficient harvestable weight and quality are produced relative to the inputs that have to be made to produce the crop. Such cost effective systems could be produced, provided this cropping system continues to be optimized (Theunissen & Schelling, 1998).

Our conclusions are that there is some evidence for active selection of monocropped over intercropped leeks by air-borne, incoming adult *T. tabaci*. However, once the adult thrips are in the crop, their density in undersown leeks is determined mainly by delayed crop colonization and host-plants quality and less by external population pressure. Larval population densities are a result of both adults migration and their subsequent feeding behaviour. This results in induced resistance against *T. tabaci* in clover undersown leek plots, where the induction of resistance is presumably caused by interaction between the root systems of the leek and the undersown clover. The latter is still our working hypothesis.

Résumé

Recherche et colonisation de la plante hôte par *Thrips tabaci* en monoculture de poireau et en poireau associé à du trèfle

Une expérience en champ a été réalisée en associant des parcelles de poireau (*Allium porum*) sans culture associée (monoculture) et des parcelles de poireau semées avec du trèfle pour obtenir une information sur la recherche et la colonisation de la plante hôte par *Thrips tabaci*. La première infestation par les adultes de thrips a lieu simultanément dans les deux conditions, monoculture et culture associée. Après quelques jours d'infestation les populations d'adultes commencent à être différentes dans les deux traitements. La population de larve de thrips qui est dépendante de la migration d'adultes, de l'alimentation et de la ponte, commence à différer entre les deux types de parcelles. Les parcelles en monoculture n'étaient pas la sources des thrips adultes ; ainsi les populations d'adultes et de larves dans les poireaux associés à du trèfle semblent être limitées par la qualité modifiée de la plante hôte qui entraînerait une résistance induite. La quantité et la qualité de la récolte dans les deux types de culture sont discutées.

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Integrated Control in Field Vegetable Crops
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Thrips damage or yield reduction in undersown leek: replacing one evil by another?

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Abstract: Intercropping could be a promising possibility for reducing pest insect populations in vegetable crops in which applications of insecticide are either restricted or relatively ineffective. Undersowing leek with living mulches was used to evaluate the mechanisms, which contribute to the commonly observed reductions in pest insect numbers. We used undersowings of *Trifolium subterraneum, T. fragiferum* and a barley straw mulch layer to test how these three treatments affected the population dynamics of *Thrips tabaci* in an autumn leek crop. We also quantified the effects of the three treatments by recording both the quality and quantity of the marketable crop. The undersown clover was drilled in rows at Braunschweig and as a full ground cover at Hannover. Both species of clover reduced the thrips infestation, irrespective of how the clover was sown. Competition from clover sown four and two weeks before the leeks were transplanted reduced crop yield by about 50% and 30% respectively. However, the two undersowing treatments produced more high quality plants when the thrips infestation was high. Differences in plant damages were observed also when thrips infestations were low, but had less impact on the overall marketable quality of the plants. We conclude that the reductions in crop yield produced by undersowing with clover will only be compensated by improvement in crop quality when thrips infestations are high.

Key words: *Thrips tabaci, Allium porrum,* undersowing, *Trifolium subterraneum, T. fragiferum*

Introduction

The onion thrips (*Thrips tabaci* Lind.) is the most important pest insect of leek (*Allium porrum* L.) crops in western Europe (e.g. Dern, 1983; Crüger & Hommes, 1990; Ester *et al.*, 1997). Leaf surfaces are damaged by both thrips adults and larvae. This results in both the quantity and quality of the leek crop being reduced at harvest. Controlling *T. tabaci* in leek crops by applying insecticides is difficult to achieve and has several limitations. Resistance to insecticides can build up extremely fast, as onion thrips populations reproduce parthenogenetically. In addition, the insecticides used for the control of thrips often do not come into direct contact with the target insects, as most of the adults and larvae are sheltered by the tightly packed leaves of the host plant.

It is expected that, after the change of the German plant protection law, to conform with the new legislation of the European Community, the costs to companies, of licensing new insecticides will exceed the expected returns from the sale of such chemicals, for use in field vegetables crops in which the area under cultivation is low. This is one of the reasons why there is so much current interest in trying to develop non-chemical methods of pest management. One possible way of reducing pest insect populations in vegetable crops, without having to apply insecticides, is to undersow the main crop. Undersowing leek with clover or ryegrass has been shown to have an adverse effect on thrips populations (Theunissen

& Schelling, 1993, 1996; Müller-Schärer *et al.*, 1992; Imhof *et al.*, Weber *et al.*, 1997). However, the cultivation of leek in an undersown system will only be accepted by the farmer if the yield reductions in plant weight caused by competition between the leek and clover plants are outweighed by corresponding improvement in the quality of the leeks at harvest. We investigated, therefore, how different undersowing systems affected the level of thrips infestations in leek crops. In addition, we compared the quantity and quality of the harvested leeks to determine whether the presumed positive effects that undersowing would have in improving plant quality would compensate sufficiently for the economic loss in total yield.

Materials and methods

In 1996, field trials using autumn leek (*Allium porrum* L. cv. Longina) were done at two different locations in Lower Saxony. One experimental field was at Ruthe nearby Hannover (530 m^2), and the other at the Federal Biological Research Centre in Braunschweig (820 m^2). We tested four treatments, each replicated six times, in a randomized block design. The four treatments were: leek undersown with ground clover (*Trifolium subterraneum* cv. Geraldton 20 kg/ha); leek undersown with strawberry clover (*Trifolium fragiferum* cv. Palestine 10 kg/ha); leek with soil covered by a barley straw mulch layer; and a monocrop of leek with bare soil (control plot). All plots were fertilized using the same amount of fertilizer after checking the residual nitrogen content using the N_{min}-method. Therefore, the nominal value of 220 kg N/ha was added to the bare soil plots. The experiments done at the two localities differed in the basic undersowing treatments. At Braunschweig, the clover were drilled in rows between the crop rows, whereas at Ruthe the clover seeds were broadcast over the entire plots. At Braunschweig and Ruthe, the clover was sown four and two weeks, respectively, before the leeks were transplanted. Each week throughout the period of crop growth, five plants were taken at random out of each plot and placed into individual plastic bags. The numbers of larval and adult thrips present were counted leaf by leaf in the laboratory. The damage was expressed as the percentage damage of the total leaf surface.

Results

Compared to the plots with bare soil both clover treatments reduced significantly the infestation levels of the onion thrips. (Figure 1). At Ruthe, there were no statistical differences in the numbers of thrips recorded from the two clover treatments. At this site, where the clover seeds were spread over the entire plot, both undersowings resulted in a pronounced reduction in the numbers of *T. tabaci*. At Braunschweig, there the undersowing was done between the leek rows, the infestation levels of the onion thrips were generally lower. Nevertheless, at this site the differences in thrips numbers between all treatments were still highly significant. As the plots with straw mulch only reduced slightly the numbers of thrips present, this option will not be incorporated into any future leek cropping system.

The development of the thrips infestations can be followed more clearly by looking solely at the populations of thrips larvae (Figure 2). In this analysis the cumulative sum of thrips larvae is

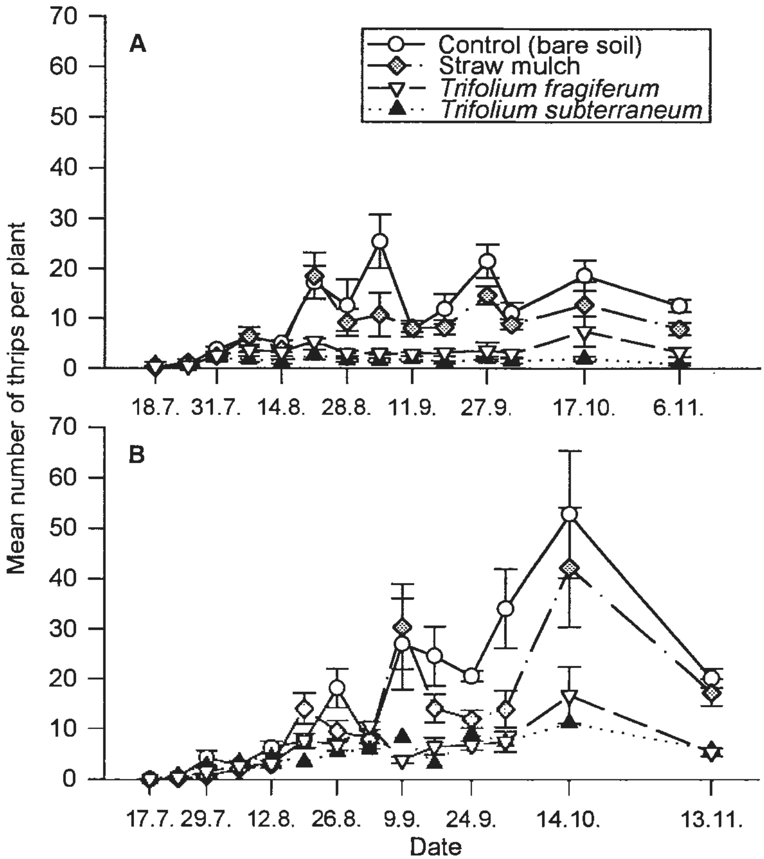

Figure 1. Mean numbers of *Thrips tabaci* (mean ± SE) recorded from undersown and mulched crops of leek; A) Braunschweig, undersowing between rows; B) Ruthe, undersowing for full ground cover (RMANOVA after log (n+1) transformation; Braunschweig; df = 3, F = 165.8, P < 0.001; Ruthe: df = 3, F - 45.6, P < 0.001).

given over the whole experimental period. Because thirty plants were inspected per treatment on each sampling date, the total number of thrips larvae per treatment was based on 390 plants. At both locations larval numbers increased greatly between the second half of August and the first half of October, indicating that egg laying activity was increased during this period even though the numbers of adult thrips found on the plants did not remain constant on the plants (compare Figure 1). In addition, during this period the slopes of the cumulative totals were much steeper for the data collected from the bare soil and straw mulch plots than from either clover treatment. At Braunschweig the increase in the numbers of thrips larvae was similar to the one recorded at Ruthe, despite the level of thrips infestation being lower (Figure 2).

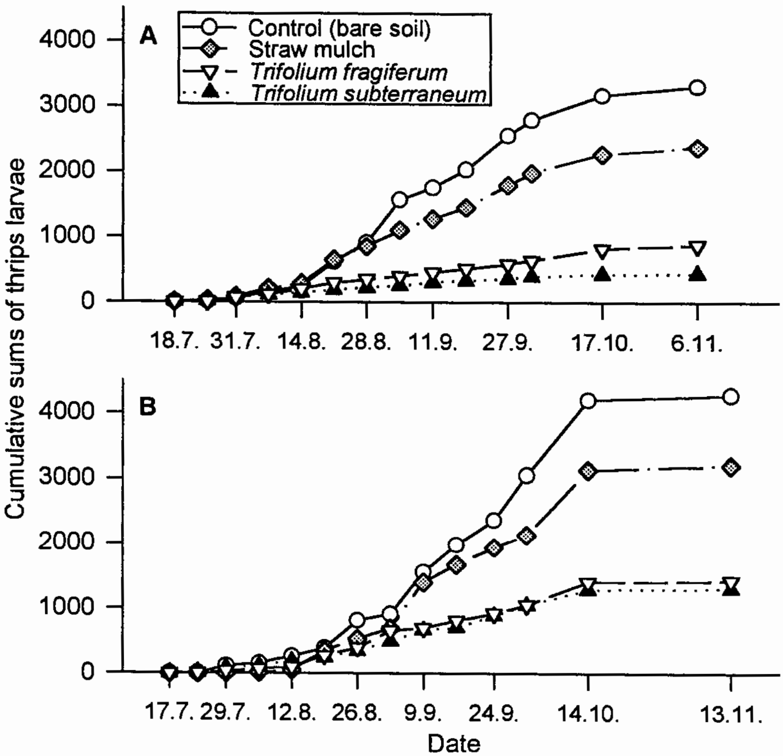

Figure 2. Cumulative totals of *Thrips tabaci* larvae (mean ± SE) recorded from undersown and mulched crops of leek A) Braunschweig, undersowing between rows; ANOVA, $F = 25.148$, $P < 0.001$; B) Ruthe, undersowing in full ground cover; ANOVA, $F = 3.886$, $P < 0.05$.

Plant yield can be expressed by using several growth parameters, such as the diameter or length of the shaft of the leek plants. At both locations (data not shown), the clover treatments reduced significantly the diameter of the market-ready plants. Calculation of either mean yield per hectare, or mean weight per plant, produced results similar to those obtained using mean diameter (Figure 3). Both undersowings produced severe reductions in yield. Although these differences were significant at Braunschweig for both clover treatments, at Ruthe the *T. fragiferum* treatment did not cause a significant yield loss. The quantitative yields from the clover plots were 30 - 50% lower than those recorded from the bare soil plots.

Because crop quality is reduced greatly by the presence of thrips damage on the plant leaves, we compared the amount of leaf damage recorded from the various treatments. At both sites, the higher numbers of thrips in the bare-soil plots produced much more leaf damage than the lower numbers of thrips found on the undersown plots (Figure 4).

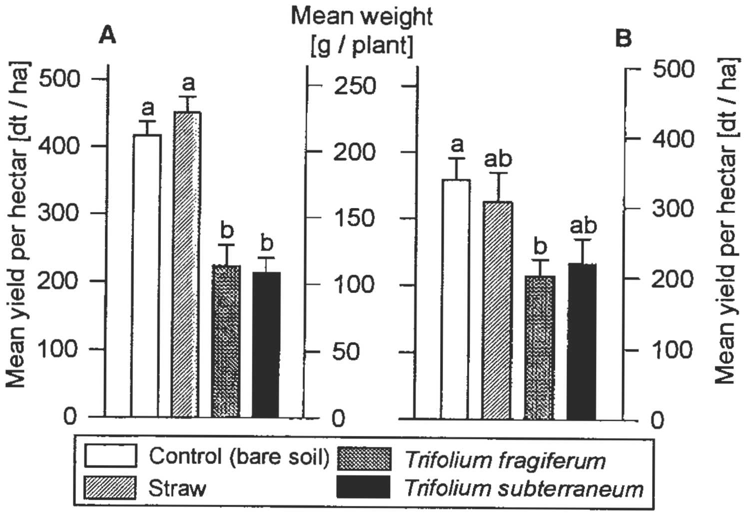

Figure 3. Effect of the different treatments on crop quantity (marketable weight; mean ± SE); A) Braunschweig, undersowing between rows, ANOVA, F = 25.148, Tukey, $P < 0.001$; B) Ruthe, undersowing full ground cover, ANOVA, F = 3.886, Tukey, $P < 0.05$.

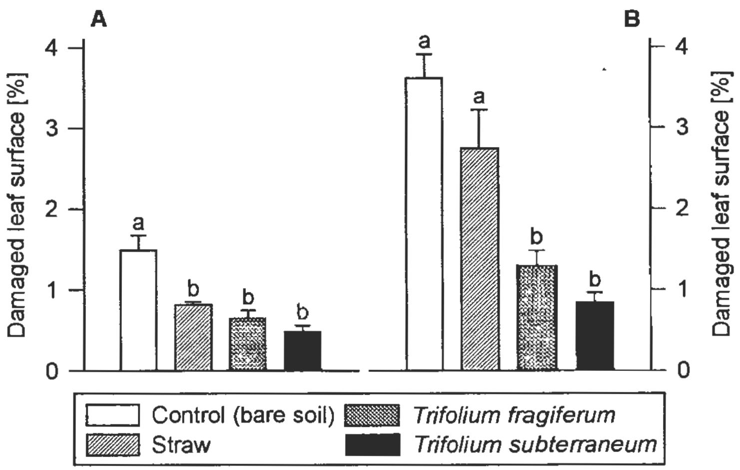

Figure 4: Effect of the different treatments on crop quality (% thrips leaf damage; mean ± SE); A) Braunschweig, undersowing between rows, ANOVA on arcsine-transformed data, F = 14.44, $P < 0.01$; B) Ruthe, undersowing full ground cover, ANOVA on arcsine-transformed data, F = 17.48, $P < 0.05$.

To relate leaf damage to economic yield, we calculated the frequency distribution of the total plant damage in the various treatments, by allocating each harvested leek to one of four quality classes. Plants in the first quality class had no leaf damages, those in the second class had less than 1.5% damage. Plants in these two classes were highly marketable. In the third class, damage ranged from 1.5 - 3.5% and in the fourth class was greater than 3.5%. Plants in these two classes were difficult to market and had to be sold at a lower price.

More high quality leeks were recorded from the undersown than from the bare-soil plots. This was especially apparent for the high thrips infestation present at Ruthe (Figure 5). The crop quality from the plots with *T. subterraneum* was more than 60% better than that from the bare-soil plots. However, even with a low thrips infestation, as at Braunschweig, crop quality was still improved by about 40%.

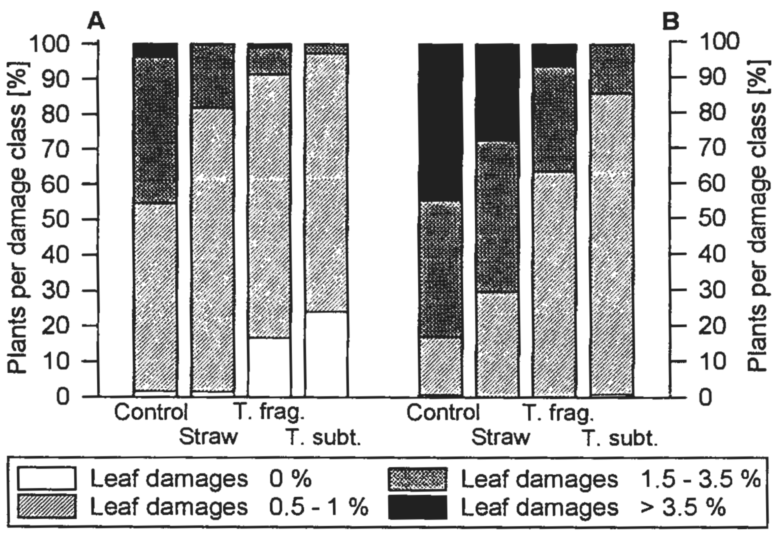

Figure 5: Frequency distribution of the marketable leeks, classified according to the amounts of thrips leaf damage recorded on the leaves; A) Braunschweig, undersown between rows; B) Ruthe, undersowing in full ground cover; T. frag. = *Trifolium fragiferum*, T. subt. = *Trifolium subterraneum*.

Discussion

Undersowing leek with clover reduced significantly the population levels of *T. tabaci*. Neither the manner of sowing (undersowing in rows or full cover) nor the clover species used affected the levels of infestation. Compared to the clover treatments, the straw mulch had only a marginal effect at the higher infestation level. Positive effects of undersowings on thrips infestation levels had been reported previously (Theunissen & Schelling, 1993, 1996; Müller-Schärer *et al.*, 1992; Imhof *et al.*, 1996). However, such studies did not separate the influence of different clover species or the manner of undersowing per se. As the increase in the cumulative numbers of thrips larvae was similar in both clover treatments, but differed significantly from the bare-soil plots, we conclude that it is solely the presence of the clover that affects the overall dynamics of the thrips population. It is the accumulation of thrips that fly around at random and are able to locate more easily the leek plants growing in bare soil, that produces the higher infestation levels over time. This confirms the "appropriate/inappropriate landings" hypothesis (Finch 1996), which is centred on the pre-alighting behaviour of herbivorous insects, and which makes colonisation of host plants by pest insects less probable in situations that involve intercropping. Unfortunately, the undersowing regimes still produced enormous losses in the weight of the harvestable leek crops. This problem was highlighted in the earlier investigations on undersown leek crops (Müller-Schärer *et al.*, 1992; Imhof *et al.*, 1996; Theunissen & Schelling, 1996). However, in the current experiment in which the clover was undersown at the later date, the differences in yield quantity were less pronounced due to the shorter period of competition. Leek is a very weak competitor early in the season, as it grows very slowly during the first few weeks (Krug, 1991). It is important, therefore, to determine accurately the timing at which the clover should be sown. Müller-Schärer *et al.*, (1992) suggested an interval of five weeks between sowing ryegrass (*Lolium perenne* L.) and transplanting the leek crops. In contrast, Imhof *et al.* (1996) reported no differences in yield when the *L. perenne* was drilled on the day the leeks were transplanted.

Better plant quality may help to compensate for the economic losses resulting from reduced plant yield. The lower infestations of thrips in undersown leek crops resulted in improved plant quality. If the damage produced by the thrips does not exceed the 1.5% level, the leek crop will have a high market value. However, the levels of crop quality that are acceptable are governed largely by the demands of the market. If the overall level of damage on the marketed leek crop is high, it is sometimes possible to market plants with damage ratings of 3 or 4%. In such situations the advantages gained from using undersowing systems will be reduced considerably. Despite this, in situations of high thrips infestations, intercropping results in greater numbers of plants in the higher quality classes. This confirms the findings of Müller-Schärer *et al.*, (1992); Imhof *et al.*, (1996); Theunissen & Schelling, (1997).

We conclude that undersowing leek with clover is an effective way of reducing thrips damage. The reductions in crop yield associated with undersowing, will only be compensated by improved plant quality, in situations where thrips infestation levels are high, and by the adoption of cultural management techniques that help to minimize the clover-leek competition. In future experiments, we will try to optimize the sowing date, to reduce yield losses and to improve the positive effects of undersowing on plant quality.

Résumé

Dégâts de thrips ou réduction de la récolte dans une culture de poireau associée à du trèfle : remplacement d'un mal par un autre ?

La culture intercalaire pourrait être une possibilité prometteuse pour réduire les populations d'insectes ravageurs dans une culture dans laquelle des applications insecticides sont limitées ou relativement inefficaces. La culture associée au poireau avec une couverture vivante est utilisé pour évaluer les mécanismes qui contribuent aux réductions du nombre des insectes ravageurs communément observés. Nous utilisons comme culture associée du *Trifolium subterraneum*, du *T. fragiferum* et de la paille d'avoine en mulch pour tester comment ces trois traitements affectent la dynamique des populations de *Thrips tabaci* dans une culture de poireau d'automne. Les effets des trois traitements sont quantifiés en notant à la fois la qualité et la quantité de la récolte commercialisable. La culture associée de trèfle est semée en ligne à Braunschweig et à la volée à Hanovre. Les deux espèces de trèfle réduisent la population de thrips indépendamment de la manière dont le trèfle a été semé. La compétition du trèfle, semé quatre et deux semaines avant la plantation du poireau, réduit la récolte d'environ 50% et

30% respectivement. Toutefois, les deux types de traitement associés produisent des plants de qualité plus élevée quand l'infestation de thrips est forte. Des différences d'attaque de plante sont observées aussi quand les infestations de thrips sont basses, mais avec un impact moindre sur la qualité totale de plantes commercialisables. Nous concluons que la réduction de la récolte produite avec une culture associée de trèfle serait seulement compensée par une amélioration de la qualité de la culture quand il y a une forte infestation de thrips.

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Insecticidal Control

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Controlling the onion fly (*Delia antiqua* (Meig.)) with insecticides applied to leek seed

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Abstract: Field experiments were carried out in 1994 and 1995 to assess the levels of control of the onion fly (*Delia antiqua*) that could be attained in a winter leek crop (*Allium Porrum* L.) by film-coating the seed with various insecticides. Plants were raised in a seed-bed. Coating the seeds with diflubenzuron, fipronil, imidacloprid and teflubenzuron gave good control, whereas coating with benfuracarb and methiocarb was only moderately effective. The most effective insecticides, fipronil and teflubenzuron, were not phytotoxic, whereas imidacloprid prevented some of the seeds from germinating. Methiocarb and imidacloprid at a rate of 56 g a.i. per unit of seed (250,000 seeds) showed a phytotoxicity effect comparable to the untreated seeds. Benfuracarb and diflubenzuron had a slightly phytotoxic effect.

Key words: *Delia antiqua, Allium porrum*, insecticides, imidacloprid, fipronil, teflubenzuron

Introduction

The onion fly, the leek moth (*Acrolepiopsis assectella*) and the onion thrips (*Thrips tabaci* (Lind.)) are the most important pests of leek crops in Western and Southern Europe (Crüger and Hommes, 1990). Adults of the spring (first) generation of the onion fly emerge in May; they lay eggs in the soil alongside the food plants. Once the eggs hatch, the larvae enter the underground part of the plant and hollow out the basal part of the leek stem which results in the plant collapsing the larvae pupate in the soil (Loosjes, 1976; Ester et al., 1992). In the field, leek plants are spaced more widely, so the onion fly is not a real problem. However, when infected plants are transplanted into the production field, such plants become very susceptible to several fungal and bacterial diseases, such as *Erwinia*. In the high plant density that occurs in the seedbed, neighbouring plants are readily attacked, and this results in patches of collapsed plants.

The insecticide benfuracarb, applied as a film-coating, has been used for some years in the Netherlands to control onion fly attacks in the seedbed (Ester and de Vogel, 1994). This paper reports on experiments to assess its efficacy when applied as a film-coat to leek seed and to develop a seeds treatment capable of controlling thrips. The aim was to find a single insecticide, that would protect the crop against both thrips and the onion fly.

As benfuracarb has no effect on thrips, several insecticides were tested against the onion fly as well. The assumption was that a systemic insecticide might also control thrips. Fipronil at a rate of 50 g a.i. per unit of seed is recommended for controlling thrips (Ester et al., 1997), as imidacloprid is phytotoxic. These insecticides were among those we tested. Our aim was to develop an acceptable method of thrips and onion fly control by film-coating seeds to protect plants in the seedbed and, preferably, for several weeks after transplanting (leek seedlings are transplanted approximately 12 weeks after sowing).

Materials and methods

Seed treatments

In 1994, the experiments were done with the winter leek variety Vrizo, which has a thousand kernel weight (tkw) of 2.36 g. In 1995, seeds of the variety Farinto, which has a tkw of 2.80 g and were provided by Nunhems Zaden BV, were used.

In both years the seeds were film-coated by SUET (Saat- und Erntetechnik, Eschwege, Germany) using a fluidised bed technique. The film-coating contained polymers that gave rise to a dust-free product. To obtain the same amount of insecticide per seed, rates were expressed as per unit of seed, in which one unit equalled 250,000 (Table 1). All treatments contained the fungicide thiram at 0.75 g a.i. per unit of seed. Untreated seeds were film-coated only with thiram.

Of the seven chemicals tested, only fipronil (tested as experimental compound EXP 80415A) and imidacloprid were known to be systemic. Benfuracarb is registered in The Netherlands for treating leek and onion seed to control onion fly. Methiocarb is an insecticide applied as a spray to control thrips. The selective insecticides diflubenzuron and teflubenzuron are registered in The Netherlands to control certain lepidopteran pests and for use in sprays against the mushroom scuttle fly *(Megaselia halterata)*. These products are used normally to control caterpillars in several outdoor crops.

Table 1. Summary of insecticides and doses [g a.i. per unit (250,000 seeds) of seed] used to film-coat leek seed to control onion fly.

Insecticide	Formulation	1994	1995
Benfuracarb	40WP	-	20
Diflubenzuron	25WP	25	-
Diflubenzuron	25WP	37.5	-
Diflubenzuron	480 g/l	48	-
Diflubenzuron	480 g/l	72	-
Fipronil	500 FS	30	-
Fipronil	500 FS	-	37.5
Fipronil	500 FS	50	50
Fipronil	500 FS	75	-
Imidacloprid	70%WS	42	-
Imidacloprid	70%WS	56	56
Methiocarb	500FS	50	-
Methiocarb	500FS	75	-
Teflubenzuron	150 g/l	12	-
Teflubenzuron	150 g/l	18	18
Teflubenzuron	150 g/l	-	27

Efficacy and seedling emergence trials

Insecticide efficacy and/or seedling emergence experiments were carried out at two locations: Breda (sandy soil) and Urk (marine loam). Infestations of onion fly can be expected each year in both areas, because leek is cultivated intensively throughout the year. The seeds were sown with a Miniair sowing machine favoured by Dutch growers of winter leek. Plots consisted of eight rows (20 cm between rows) each 4-5 m long (1.7 cm between seed). The seed was sown in mid-April in 1994 and at the end of April in 1995. Film-coating with imidacloprid was tested in 1994 and with imidacloprid and benfuracarb in 1995. The experimental layout consisted of a randomised block with each treatment being replicated four times. Data were analysed using analysis of variance (ANOVA) in Genstat 5. From the ANOVA means, least significant differences (LSD) and F-probabilities were obtained. LSDs were calculated with Student's t distribution.

Efficacy and emergence assessment

Damage to crops from onion fly attack was assessed by recording the percentage of plants found collapsed between seven and thirteen weeks after sowing. Seedling emergence in both years was recorded by counting six rows of one metre long per replicate at the end of May.

Germination test

A laboratory germination test was carried out in silver sand at 15°C and with a 12 h photoperiod. A completely randomised block design was used, and involved six replicates each of 60 seeds. The number of well-developed plants was determined 9, 12 and 15 days after sowing. The statistical analysis was performed with a Genstat package.

Results

Germination

At both rates, on the assessment made on day 9, both imidacloprid and methiocarb delayed germination (Table 2). Fipronil at 30 and 50 g a.i. per unit of seed and both rates of teflubenzuron also slightly delayed germination after nine days. Diflubenzuron had no effect on germination at nine days. After 12 days, imidacloprid, at the rate of 56 g a.i., and methiocarb at both rates, allowed fewer plants to germinate than in the untreated seeds. The percentage of normal plants from the various batches of treated seeds did not differ significantly after 15 days. Imidacloprid and methiocarb, at both rates, and diflubenzuron at the rate of 37.5 g a.i. per unit of seed, gave rise to smaller plants (p = 0.05) than the untreated seeds. Imidacloprid, at the rate of 56 g a.i., produced a dose response effect that was visible both in seedling emergence and in plant height.

At Breda, diflubenzuron, methiocarb and fipronil, but only at the rate of 75 g a.i. per unit seed, resulted in a fewer plants/metre than from the untreated seeds (Table 3). At Urk, only diflubenzuron (72 g a.i.) and imidacloprid (56 g a.i. per unit seed) lowered the number of plants that germinated. In 1995, imidacloprid (56 g a.i.) and fipronil (50 g a.i. per unit of seed) both lowered the numbers of plants that germinated/m of row.

Coating the seed with insecticides reduced (p = 0.05) onion fly damage when compared to the untreated control (Table 4). However, methiocarb and benfuracarb did not provide sufficient crop protection.

Table 2. Laboratory germination of film-coating winter leek seeds in 1994. Percentage of plants after 9 and 12 days; percentage of normal plants with mean plant height (cm) after 15 days.

Insecticide		g a.i./ unit seed	9 days	12 days	15 days N	15 days cm
Untreated	- coating	0	75	97	92	4.3
	+ coating	0	70	92	93	4.7
Diflubenzuron	25WP	25	68	94	94	4.2
		37.5	66	90	93	3.8
Diflubenzuron	480 g/l	48	71	94	94	4.1
		72	64	94	96	4.3
Fipronil		30	49	92	90	4.3
		50	49	92	92	3.8
		75	59	96	90	4.2
Imidacloprid		42	23	89	87	3.5
		56	10	83	87	2.7
Methiocarb		50	2	71	90	2.4
		75	6	81	92	2.4
Teflubenzuron		12	44	94	96	3.7
		18	46	93	93	3.7
LSD ($\alpha = 0.05$)			13	6	6	0.4

Table 3. Emergence of winter leek seeds in the field. Number of seedlings recorded/m of row 5-weeks after drilling at Breda and Urk in both 1994 and 1995.

Insecticide		g a.i./ unit seed	1994 Breda	1994 Urk	1995 Breda	1995 Urk
Untreated		0	54	28	47	63
Benfuracarb		20	-	-	46	59
Diflubenzuron	25WP	25	49	-	-	-
		37.5	49	-	-	-
Diflubenzuron	480 g/l	48	-	27	-	-
		72	-	22	-	-
Fipronil		30	-	29	-	-
		37.5	-	-	47	56
		50	52	26	45	42
		75	50	27	-	-
Imidacloprid		42	51	26	-	-
		56	51	20	41	43
Methiocarb		50	46	-	-	-
		75	44	-	-	-
Teflubenzuron		12	-	28	-	-
		18	-	31	47	47
		27	-	-	44	49
LSD ($\alpha = 0.05$)			3	5	5	17

Table 4. Efficacy of the insecticides applied as a film-coat for controlling onion fly in leek crops. Percentages of damaged plants 13 weeks after drilling in 1994 and 10 weeks after drilling in 1995 at Breda and Urk.

Insecticide		g a.i./	1994		1995	
		unit seed	Breda	Urk	Breda	Urk
Untreated		0	9.8	5.0	23.6	11.2
Benfuracarb		20	-	-	5.2	6.0
Diflubenzuron	25WP	25	1.0	-	-	-
		37.5	0.7	-	-	-
Diflubenzuron	480 g/l	48	-	0.7	-	-
		72	-	0.2	-	-
Fipronil		30	-	0.4	-	-
		37.5	-	-	0.0	0.0
		50	0.2	0.2	0.0	0.0
		75	0.2	0.1	-	-
Imidacloprid		42	0.8	1.4	-	-
		56	0.4	0.9	0.0	0.6
Methiocarb		50	2.7	-	-	-
		75	1.8	-	-	-
Teflubenzuron		12	-	0.8	-	-
		18	-	0.5	0.0	0.2
		27	-	-	0.0	0.0
LSD ($\alpha = 0.05$)			2.9	2.1	5.3	3.3

Discussion

The aim of insect control is to avoid economic crop losses. This research demonstrates that coating seed with insecticide was sufficient to control the onion fly in leek crops. However, of the compounds tested, benfuracarb and methiocarb failed to give sufficient protection in several trials. The benfuracarb results contradict of those recorded in 1991 and 1992 (Ester and de Vogel, 1994) and suggests that carbamate insecticides cannot be relied on to give sufficient protection against the onion fly in leek crops. When the insecticides were applied as a seed treatment, carbofuran was also not effective. Benfuracarb has been used to treat onion seed for many years, so it is possible that the onion fly has built up resistance to this compound. Narkiewicz-Jodko (1991) reported successful control of onion fly in onion by applying carbosulfan or isofenphos as a seed-coating. It might, however, be possible to reduce the risk of insecticide resistance developing in onion fly, by deploying the entomophagous nematode *Steinernema bibionis*. Promising results have been obtained using this approach (Coomans and De Grisse (1985)). When they applied *S. bibionis* to leek plants to control larvae of the onion fly they found that 400 nematodes per plant reduced the damage and that after three days they caused no further damage. Another application to control the onion fly is the sterile insect technique, which has been introduced in practice in The Netherlands already for many years. In some regions mainly onion growers but also a few leek growers used this system by applying sterilised onion flies (Loosjes, 1976).

In the present study, diflubenzuron both as a 25WP and 480 g/l EC formulation, fipronil, imidacloprid and teflubenzuron reduced the level of onion fly attack to less than 1% in both years. The phytotoxic effects of methiocarb and imidacloprid that occurred when 56 g a.i. were applied per unit of seed were recorded in the 1994 and 1995 field trials have also been observed in the laboratory. Diflubenzuron (480 g/l formulation) at the highest rate was phytotoxicity in the 1994 field trial. Diflubenzuron 25WP, 480 g/l lowest dosage, fipronil and teflubenzuron gave control of the onion fly without phytotoxicity. Film-coating leek seeds with diflubenzuron (25WP) at a rate of 25 g a.i. and 37.5 g a.i., diflubenzuron (480 g/l) at a rate of 48 g a.i., fipronil from 30 - 75 g a.i. and teflubenzuron at rates of 12 - 27 g a.i. per unit of seed illustrated clearly that the amounts of insecticide required to control the onion fly in leek crops can be reduced. The general conclusion is that it is possible to control the onion fly by treating leek seed with diflubenzuron (25 WP) at a rate per unit seed of 25 g a.i., diflubenzuron (480 g/l) at a rate of 48 g a.i., fipronil at a rate of 30 g a.i., imidacloprid 42 g and teflubenzuron 12 g a.i.

An unexpected finding was that the growth-regulator group of insecticides developed to control caterpillars (lepidopterous) (van Eck, 1981) are also extremely effective in controlling Diptera, such as the onion fly. It would be interesting to know whether the leek moth *Acrolepiopsis assectella* is also affected when these compounds are applied as seed treatments. Compounds of this type are more environmentally acceptable than the other groups, and should be recommended if thrips do not need to be controlled.

If both thrips and onion fly have to be controlled in leek crops, it is recommended that the insecticide fipronil should be applied at a rate of 50 g a.i. per unit of seed. Fipronil is expected to be available in 1999 in The Netherlands to be used in film-coating techniques for treating leek seed.

Résumé

Protection contre la mouche de l'oignon (*Delia antiqua* Meig.) au moyen 'insecticides appliqués aux semences de poireaux

Des expérimentations au champ ont été réalisés en 1994 et 1995 pour estimer les niveaux de contrôle de la mouche de l'oignon (*Delia antiqua*) qui pourrait s'attaquer aux poireaux d'hiver (*Allium porum* L.) traités par enrobage des semence avec différents insecticides. Les plantes ont été plantées en chassis. L'enrobage des graines avec le diflubenzuron, le fipronil, l'imidacloprid et le teflubenzuron donne de bons résultats alors que le benfuracarb et le methiocarb sont moins efficaces. Pour les insecticides efficaces, le fipronil et le teflubenzuron sont non phytotoxiques, tandis que l'imidacloprid empêche quelques graines de germer. Le methiocarb et l'imidacloprid, aux taux de 56 g de matière active par unité de semence (250 000 graines), montrent une phytotoxicité comparable aux graines non traitées. le benfuracarb et le diflubenzuron ont un effet légèrement phytotoxique.

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Effectiveness of insecticide applied to carrot foliage in killing carrot fly

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Abstract: Cage tests were done under glasshouse conditions to determine whether residues from pyrethroid insecticides, sprayed onto carrot foliage, were capable of killing high numbers of the carrot fly. The overall aim was to find insecticides to replace the organophosphorus compounds applied currently to UK carrot and parsnip crops, as the residues of such compounds have reached unacceptable levels in a few carrot crops in recent years. Lambda-cyhalothrin and deltamethrin appear to be the two most useful pyrethroids to use as alternatives to triazophos, the organophosphorus insecticide used currently to reduce carrot fly damage in many UK crops. Before triazophos is replaced, however, it would be prudent to test whether the levels of control achieved by spraying triazophos, which kills the young larvae, can be matched by the new pyrethroids, whose main affect is to kill adult flies.

Key words: *Psila rosae,* insecticide residues, lambda cyhalothrin, deltamethrin

Introduction

The growing concern about the effects of insecticides on the environment and their perceived health hazard to consumers, have focussed research on to ways of reducing the amounts of insecticide applied to field vegetable crops. The current challenge is to apply the optimum amount of the appropriate insecticide at the correct time.

Unfortunately, little is known about the mode of action of the insecticides sprayed to control the carrot fly under field conditions. If the insecticide spray hits the flies directly, there may be a considerable "knock-down". This effect depends largely on the insecticide used. For example, in 1985, Harris *et al.* showed that cypermethrin and deltamethrin were respectively 3 and 22 times more effective in "knocking down" adult carrot flies than diazinon.

However, as only a small proportion of the flies are likely to be hit the residues of insecticide are likely to be more important in controlling this fly. Such residues may be left either on the plant foliage or on the soil, and may affect the egg, larval and/or adult stage. In 1992, Dufault showed that residues of diazinon on the soil had the potential for killing not only the flies but also the eggs and larvae. He also indicated that residues of cypermethrin on the soil were toxic to adult carrot flies, but he did not test how long the effect lasted

In this study, instead of looking at the effects of insecticides once they reach the soil, an aspect studied already in some detail (Chapman *et al.*, 1981; Harris *et al.*, 1981; Cheng, 1984), we concentrated on whether the residues of insecticide left on the plant foliage (Willis & McDowell, 1987) killed appreciable numbers of flies.

Materials and methods

In May 1997, plots of carrots, that had overwintered and started to produce leaves, were sprayed with seven insecticides at the rates shown in Table 1. In the first experiment, lambda-cyhalothrin and triazophos were sprayed on 1 May, at rates of 300 litres and 950 litres of water/ha, respectively, on two plots each approximately 60 m^2. At the time, the carrot foliage was *c.* 10-15 cm high. A similar area of carrots was sprayed only with water and a wetting agent. Carrots from this area were used for the "control" treatment.

Table 1. The six insecticides tested together with their rates of application.

Active ingredient (a.i.)	Formulation	Product/ha	a.i./ha (g)
Lambda-cyhalothrin	Hallmark (50 g a.i./l)	300 ml	15
Permethrin	Permasect (230 g a.i./l)	65 ml	15
Cypermethrin	Ashlade cyper. (100 g a.i./l)	150 ml	15
Deltamethrin	Decis (25 g a.i./l)	600 ml	15
Triazophos	Hostathion (420 g a.i. /l)	2500 ml	1050
Exp. 60720A	80% WG (800 g a.i/kg)	500 g	400

For the second experiment, plants in the same field were sprayed on 20 May with four pyrethroid insecticides and a new formulation, Exp. 60720A – Rhône-Poulenc, of an existing insecticide belonging to the phenyl-pyrazol group. Carrot plots, about 4 m^2, were each sprayed with one treatment. At the time, the carrot foliage was *c.* 20 cm high. The four pyrethroids were sprayed at the rate of 300 litres of water/ha using the same a.i./ha as that recommended for lambda-cyhalothrin (15g) and Exp. 60720A at the rate suggested by Rhône-Poulenc (Table 1). "Untreated" carrots were taken from a plot sprayed only with water and the wetting agent.

At intervals after spraying, the numbers of plants required for the various tests were lifted from the field. The roots were washed, cut across at approximately 5 cm below the base of the leaves, and placed into 100 ml glass jars filled with water. The neck of each test carrot was surrounded with cotton wool both to support the test plant and to prevent flies from drowning. The plants were placed into ventilated cylindrical cages whose bases were covered with damp sand. Standard fly food (Finch & Coaker, 1969) was supplied throughout the experiment. In the first experiment, 50 carrot flies were released into each cage on the day the plants were sprayed, and 25 flies/cage on the following day. On all other occasions, 20 flies were released into each cage. The number of dead flies were counted one day later. Flies were counted as "dead" if they were unable to escape (fly or walk) after being pushed with forceps. In the first experiment, the numbers of dead flies were assessed also visually, prior to the final counts, to determine if it was necessary to actually pick the "dead" flies out of the cages.

Both experiments were done in a greenhouse in which the maximum temperature varied between 18-30 °C. The first experiment with lambda-cyhalothrin, triazophos and the unsprayed treatment involved 30 cages, with ten replicates/treatment. The caged plants were placed in five rows, with two plants from each treatment being positioned at random in each row. In the second experiment, four pyrethroid treatments, the test compound Exp. 60720A, and the insecticide-free control treatment, were each replicated five times and the thirty cages used were positioned at random within five rows.

The cylindrical test cages, each 32 cm high and 16 cm in diameter, were made from sheets of polyvinyl chloride. The cage bottoms consisted of 6 cm high white plastic dishes half -filled with dry silica sand. The bottles holding the carrot plants and the tubes containing the standard fly food (Finch & Coaker, 1969) were pressed into the sand and then 100 ml of water was added to the sand in each cage. The cage tops were made from dishes similar to those used for the cage bottoms, but with the middle replaced with a gauze mesh to increase ventilation.

Flies were collected from six large (6 m x 3 m x 2 m high) field cages that had been erected, specifically for this purpose, over a plot of severely infested carrots. Pupae that had been collected from the same field and stored during the winter in a domestic refrigerator (4°C), were also buried in the soil in one of the cages to supplement the "natural" population.

Results

Most of the dead flies were found on the sand, however, some were found in the water droplets that condensed on the lower part of each cylinder and a few were found among the plant foliage or on the cotton wool. It proved difficult to obtain exact visual counts, especially when there was condensation on the inside of the cylinder. Also, some of the flies that appeared dead, especially in the pyrethroid and triazophos treatments, were not dead when touched with the forceps. In cages in which the plants had been sprayed with Exp. 60720A, the dead flies were found usually close together in cracks in the sand. Therefore, the visual assessments did not give reliable results, and so all subsequent data were based on real counts.

In the first experiment, about 90% of the flies died when they were exposed on the day of treatment, or one day later, to carrot foliage sprayed with triazophos (Figure 1). Although no

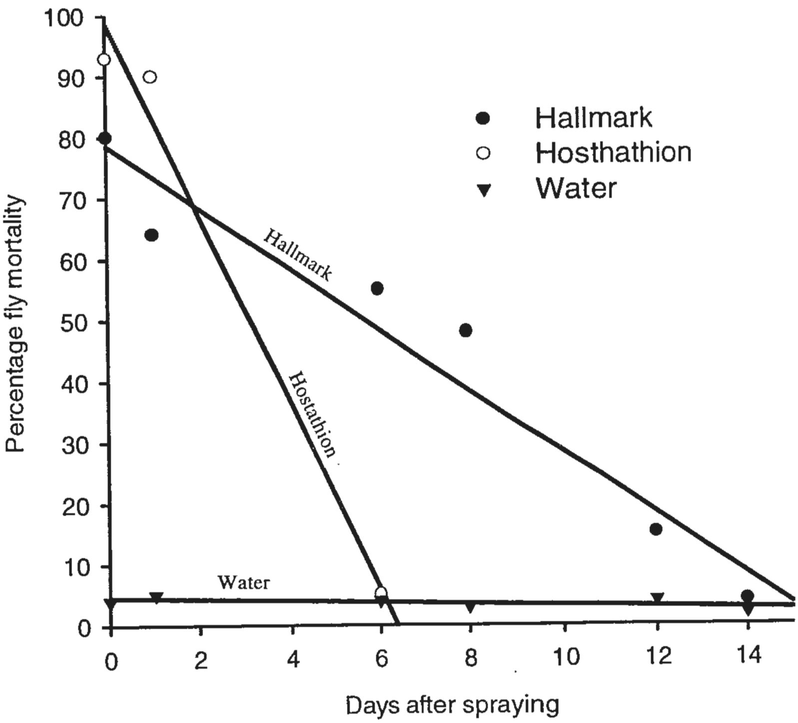

Figure 1. The percentage of carrot flies killed after being caged for 24 h with carrot foliage sprayed 0-14 days earlier with either Hallmark (lambda- cyhalothrin) or Hostathion (triazophos).

rain fell within 24 hours of applying the spray, 64 mm was recorded during the following 13 days. Carrot foliage presented to flies six days after it had been sprayed with triazophos failed to kill any flies. Unfortunately, no trials were carried out between day-1 and day-6, and so the exact duration of bioactivity remains unknown. In contrast, lambda-cyhalothrin killed about 80% of the flies on the day of spraying, and more than 50% of the flies six days later (Figure 1). This insecticide ceased to be effective after about two weeks.

In the second experiment (Figure 2), approximately 80% and 50% of the flies introduced on day-2 and day-9 were killed by the residue of lambda-cyhalothrin. No residual effect was apparent after three weeks. Although there was a heavy shower of rain about two hours after the plots were sprayed, less than 1mm was recorded during the next 14 days.

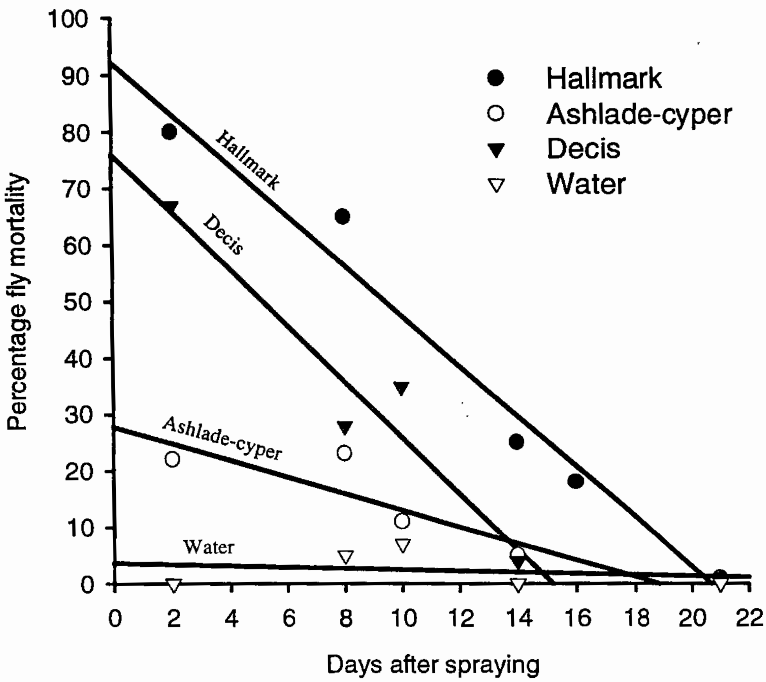

Figure 2. The percentage of carrot flies killed after being caged for 24 h with carrot foliage sprayed 0-21 days earlier with either Hallmark (lambda-cyhalothrin), Decis (deltamethrin) or Ashlade-cyper (cypermethrin).

Of the two other pyrethroids tested, only deltamethrin killed more than 50% of the flies (Figure 2). Mortality was about 65% two days after treatment and dropped to below 50% by about day-5. Also, an effect was still apparent even two weeks after spraying. The relationship between percentage mortality and time after spraying was parallel to that for lambda-cyhalothrin. Plants treated with cypermethrin killed only about 20% of the flies two days after the plants had been sprayed, but continued to kill some flies for up to 14 days. Even two days after spraying, plants sprayed with permethrin did not kill any flies and so the data for permethrin have not been included in Figure 2.

The compound Exp. 60720A appeared to have an extremely persistent biological effect. Although the test dose killed only 30% of the flies introduced on day 2, it continued to kill more than 20% of the flies when tested three weeks later. Even after four weeks, the effect was still measurable.

Discussion

Insecticides that impact with plant surfaces may be adsorbed, absorbed, altered, volatilized or removed subsequently by irrigation or rainfall (Willis & McDowell 1987). Normally such processes produce an initial rapid decline in the amount of residues on the plant surface followed by a slower, asymptotic decline. In general, pyrethroid insecticides persist longer on foliage than organophosphorus insecticides. According to Willis & McDowell (1987), the average of the published data on field half-lives was 5.3 days for the pyrethroid and 3.0 days for the organophosphorus insecticides. In the current tests, the 50% mortality from the lambda-cyhalothrin treatment was about 7-10 days in both experiments, so the current data compare favourably with those published earlier.

The experimental compound Exp. 60720A appeared to be too persistent for use in carrot crops, as its effectiveness had only halved even four weeks after it had been sprayed. When this is coupled with the fact that the leaves of the carrot plants had grown considerably during this period then much of the loss of effectiveness could have been due simply to a dilution effect. Balança & Visscher (1997) found a different formulation of compound Exp. 60720A to be highly effective against the desert locust but, because of its marked persistence, it also caused a high mortality in associated non-target insects.

Only lambda-cyhalothrin and triazophos are recommended for use in carrot crops. As there are no official recommendations for using the other pyrethroids in carrot crops in the UK, these chemicals were applied using the same amount of active ingredient as that applied for lambda-cyhalothrin. This is probably the main reason for the differences in effectiveness of the various sprays, as the pyrethroids developed recently, such as lambda-cyhalothrin, are applied at much lower rates than those developed earlier.

The environmental factors that affect the persistence of insecticides are wind, rain, temperature, sunlight, relative humidity and dew. In general, rain has the most dramatic effect on pesticide residues on plants, especially if rain occurs within 24 hours of application (Willis & McDowell 1987). Therefore, less rainfall could explain the more persistent bioactivity in the second than in the first experiment, despite pyrethroids being less affected by rain than the organophosphorus compounds (Pick *et al.* 1984).

Dufault (1994) showed that when 10 mm of rain fell within one day of a foliar application of diazinon, most of the insecticide ended up in the surface layer of the soil, which is probably what happened to the triazophos, another organophosphorus compound, applied during the first experiment. Dufault (1992) showed also that foliar residues of cypermethrin, applied at the same rate as in the current experiments, were not removed by rain and still killed adult flies for up to 15 days after the spray had been applied. Similar levels of persistence were achieved with cypermethrin in the current experiments, but the levels of control were much lower, as our experiments were done during the much higher temperatures of late-May and early-June, whereas those of Dufault (1992) were done during October. In general, low temperatures enhance considerably the effects of pyrethroids (Harris & Kinoshita 1977, Grafius 1986, Turnbull & Harris 1986).

Lambda-cyhalothrin and deltamethrin would probably be the two most useful pyrethroids to apply as replacements for the organophosphorus insecticides, triazophos. To be as effective as lambda-cyhalothrin, the dose rate of deltamethrin would probably have to be increased from about 15 to 20g a.i./ha. (see Table 1). Before triazophos is replaced, however, it would be prudent to test whether the overall control achieved using triazophos, which kills mainly young larvae hatch from the eggs, can be matched by the new pyrethroids, whose main affect is to kill the adult flies.

Résumé

Efficacité des insecticides appliqués sur le feuillage pour tuer la mouche de la carotte

Des tests en cage ont été fait sous serre afin de déterminer si les résidus des insecticides pyréthrinoides, appliqués sur le feuillage, sont capable de tuer un nombre élevé de mouche de la carotte. Le but final est de trouver des insecticides de remplacement aux produits organophosphorés appliqués couramment sur les culture de carottes et de panais en Angleterre, puisque les résidus de ces composés ont atteint des niveaux inacceptables sur cultures de carottes ces dernières années. Le lambda-cyhalothrine et la deltamèthrine semblent être les deux pyréthrinoides les plus employés comme alternatifs au triazophos, l'insecticide organophosphorés le plus souvent utilisé pour réduire les dégâts de mouche de la caròtte dans beaucoup de cultures anglaises. Avant de remplacer le triazophos, il serait prudent de tester si les niveaux de protection donnés par les pulvérisations de triazophos, qui tuent les jeunes larves, peuvent être égalés par les nouveaux pyréthrinoides, dont l'action principale est de tuer les adultes de mouche.

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Biology and control of the leek mining fly, *Napomyza gymnostoma*

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Abstract: In 1994, an insect pest, *Napomyza gymnostoma* (Loew) (*Diptera; Agromyzidae*), established itself in the eastern parts of Austria. It has now become a serious pest of leeks (in autumn) and chives. The main injuries are feeding punctures in chives and the presence of fly puparia within leek leaves, which makes the plants unmarketable. The serpentine mines are often interrupted and are found mainly in the lower parts of the hostplant. *N. gymnostoma* has a bivoltine life-cycle with generations in the spring and autumn. In 1997, the peaks of fly emergence occurred on 28 April and on 16 September. In summer there is a long period during which no flies emerge. Hence this pest appears to aestivate. At a constant temperature of 20°C, development (egg/adult) took 73 days at photoperiods of 6-10 hours, and 112 and 120 days, respectively, at photoperiods of 14 and 18 hours. Postdiapause development was induced by changes in temperature, but not photoperiod. The lower threshold temperature for development is between 3.2°C and 5.1°C. Chive is highly suitable as a host plant, as it remains vegetative for most of the year and so its leaves are available to both the spring and autumn generations of the flies. Experiments on chemical control showed that Heptenophos (330g a.i./ha) and Phosalone (420g a.i./ha) were the most effective insecticides for controlling larvae of *N. gymnostoma*. The current advice is to apply sprays as long as larvae are found feeding in the upper parts of the leafs. To control this pest without applying insecticides, farmers are advised to grow leek as far away as possible from chive. They are advised also to cover their leek crops with nets as soon as the flies of the autumn generation emerge, and to bury any plant remains containing fly pupae as deep as possible in the soil. A warning service for *N. gymnostoma* was established in Austria in 1997.

Key words: *Napomyza gymnostoma, Allium* spp., voltinism

Introduction

The agromyzid fly *Napomyza gymnostoma* (Loew) has been recorded from many parts of Europe (Hendel, 1935; Hering, 1937; Spencer, 1976). According to Hendel (1935), it lives on *Allium* species, but causes little injury. Von Tschirnhaus (1994) found specimens in warm and dry habitats in Germany and assumed that the fly was restricted to *Allium* growing in such habitats. In 1987, however, heavy infestations of this fly were found on leek crops in Hungary (Darvas & Szarukán & Papp, 1988). From 1992 onwards, damage from this pest was also reported in Slovakia (Vlcková, 1995) on crops of onion, leek and garlic. Therefore, this species (or at least this biotype) seems to be increasing its area of distribution. The fly causes problems by its pupae remaining inside the plants, by feeding punctures of adults and by the larvae rupturing plant tissues (Darvas *et al.*, 1988; Vlcková, 1995). Normally, there is spring generation (pupation at the end of May) and an autumn generation (adults in August/September, larvae in September) (Darvas *et al.*, 1988, Vlcková, 1995). The aim of this paper is to provide a report of the current situation in Austria, and to use phenological data to determine how best to control this pest.

Materials and methods

Host-plants containing fly pupae were collected at Fuchsenbigl, situated 50 km east of Vienna, in an area noted for its hot, dry summer. Chive had been grown in this area for more than 20 years, on an area of 300 m^2.

The timing of emergence of adults of *N. gymnostoma* was also recorded at Fuchsenbigl. Two cages, measuring 0.4m x 0.6m, were erected to cover a total of 1.2 metres of row in a chives crop. The cages were set-up at the beginning of April for the spring generation and in the middle of June for the autumn generation. The numbers of flies present were recorded every 1, 2 or 3 days, depending on temperature.

To test how photoperiod affects the time the flies need to complete their development, a stock culture of flies was reared in the laboratory under autumn conditions (18°C, 8h light/16h dark). Batches of flies were then allowed to lay for 3 days on 36 pots of chives to produce the fly eggs required for the subsequent experiments. Day 2 was considered to be the "actual" day on which the eggs were laid. The pots were divided into 4 groups, each containing 9 plants. Each group of plants was placed into a separate growth chamber and maintained at a constant temperature of 20°C, a light intensity of 2kLux and photoperiods of 6/18, 10/14, 14/10 or 18/6 (light/dark). The numbers of flies that emerged from the potted chives were recorded every 1-3 days. The time for 50% of the flies to emerge was used to compute any differences between the various treatments.

To study the influence of temperature on postdiapause development, on 27 February 1997, a batch of heavily-infested chives was collected from the field and placed into growth chambers maintained at temperatures of 7.5°C, 10°C and 13°C. A second batch of infested plants was placed into growth chambers maintained at 10°C, 15°C, 20°C and 25°C on 3 April 1997. The time for 50% of the flies to emerge was recorded. The rate of development was computed as the inverse function of the numbers of days needed for 50% of the flies to emerge. In a separate experiment to test the influence of photoperiod on postdiapause development, heavily-infested chives were collected from the field on 2 April 1997 and placed immediately into the rearing chambers. These plants were maintained at a constant temperature of 18°C and at photoperiods of 6/18, 10/14, 14/10 and 6/18 (light/dark). The time, in days, for 50% of the flies to emerge was recorded and its reciprocal was used to compute and compare the differences between the various treatments.

Several insecticides were tested in field-trials that involved 10m^2 plots. The tests were done at Fuchsenbigl using a randomized block design and two replications in two successive years. The insecticides were applied on 23 May 1995 and on 4 September 1996. They were applied from a portable backpack sprayer at a rate of 600 1 water/ha: "Hostaquick" [330g Heptenophos/ha], "Rubitox flüssig" [420g Phosalone/ha], "Phosdrin EC" [96g Mevinphos/ha], "Lannate 25 W" [150g Methomyl/ha], "Asystin Z" [258g Vamidothion/ha] and "Roxion S" [150g Dimethoate/ha]. Seven days after the insecticides were applied, 20 leaves that contained fly larvae, were collected from each plot so that the numbers of living and dead larvae in each treatment could be counted with the aid of a stereomicroscope.

Results and discussion

The first damage in Austria was recorded from a leek crop in the Vienna area in October 1994. Following this initial outbreak, damage has been recorded each year with increasing frequency. Damage is reported now from the eastern parts of Austria (provinces of Lower Austria and Burgenland) alongside the Pannonian Basin, whereas the western parts of the country seem to be unaffected by this pest.

Damage has been restricted mainly to leek and chive crops, and has been recorded only rarely on garlic and onions. On chive, feeding punctures and mines are the main signs of damage, whereas with leek the pupae inside the plants make them unmarketable. In garlic the lower plant parts burst alongside the larval feeding-mines as a result of growth.

In chives, the shape of the mines can be seen very clearly: they start at the upper part of the leaf and wind downwards, growing larger and larger. They often disappear for long distances and appear to continue in the deeper parenchymatic layers of the leaf. In contrast, the mines in leek and garlic are barely detectable - probably because of the thickness of the leaves. As a consequence, damage in leek and garlic is usually observed at a very late stage, when the puparia have already formed within the plants.

During the cultivation of chives, green leaves are available continuously for the leek mining larvae of both the spring and autumn generations. In addition, insects that pupate in the lower part of the plant leaves are left on the host plants in the field, whereas with leek or garlic crops the whole plants, plus pupae are harvested. It seems, therefore, that chive is a very good host plant for the leek mining fly.

The phenology of the adult flies was monitored in 1997 using emergence cages. The results are shown in Figure 1. In the spring, flies started to emerge on 16 April and continued to emerge during the following 26 days. Peak emergence occurred on 28 April. In the autumn, flies started to emerge on 10 September. Emergence lasted for three weeks and peaked on 16 September. Figure 1 is based on capturing 105 flies in the spring, and 71 in the autumn. The number of flies caught/sampling period have been expressed as a percentage of the overall total. Figure 1 shows that two generations occur, one in spring and one in autumn. The two generations are separated by a long period of nearly 3 months, during which no flies emerge, and so the insects must aestivate. A similar bivoltine life-cycle has also been reported for the agromyzid fly *Phytomyza chaerophylli* (Frey, 1991).

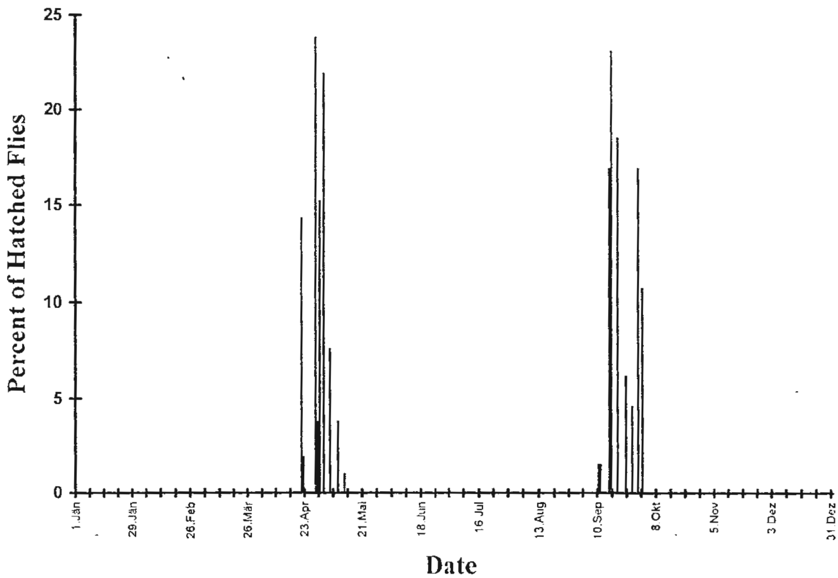

Figure 1. Emergence of the leek mining fly, *Napomyza gymnostoma*, from the soil at Fuchsenbigl during 1997.

N. gymnostoma was reared on its host-plant in the laboratory. The duration of development was recorded at 20°C under different photoperiods. As all stages develop inside the plant, only the entire developmental period from egg-laying to eclosion of adult was recorded. The results are shown in Figure 2. At photoperiods of 6-10 h, development took about 73 days. Similarly, at photoperiods of 14h and 18h development took 113 days and 123 days, respectively. As larvae of the leek mining fly are present in the field during May and September, they are subjected to photoperiods of 16.5 hours in the spring and 12.1 hours in the autumn. In this case it seems that under such summer-conditions the insects enter aestivation. It was not possible to rear the leek mining fly continuously at 20°C (without diapause) at any of the photoperiods tested.

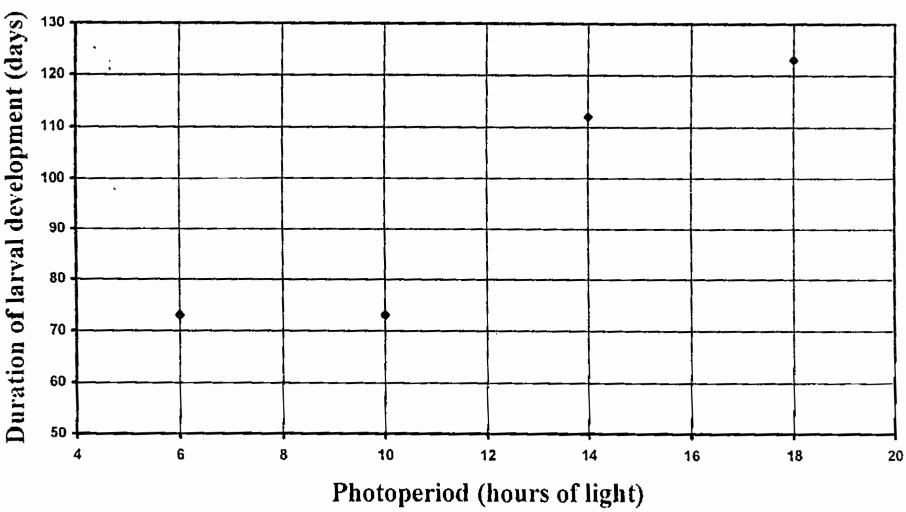

Figure 2. The duration of the period of larval development of *Napomyza gymnostoma* at photoperiods of 6, 10, 14 and 18 hours.

To study post-diapause development, pupae were brought in from the field and placed into growth chambers at two times (27/2/97 & 3/4/97) during early 1997. The results are shown in Figure 3. In both experiments the values recorded fall on straight lines, which cross the abscissae at 3.2°C and 5.1°C, respectively. These values are the lower thresholds for development. The reasons for the divergence of the two values cannot be explained, but it is possible that the lower threshold of development changes during the course of postdiapause development. It should be noted also, that the slope of the two lines is not the same. This could simply reflect the fact that at the start of these experiments the pupae collected had reached different stages of development. The influence of photoperiod on postdiapause development was tested in another experiment. When pupae were incubated on 2 April 1997 at 20°C, half of the flies emerged after 9 days, irrespective of the photoperiod they were maintained at. Therefore, postdiapause development was triggered mainly by temperature,

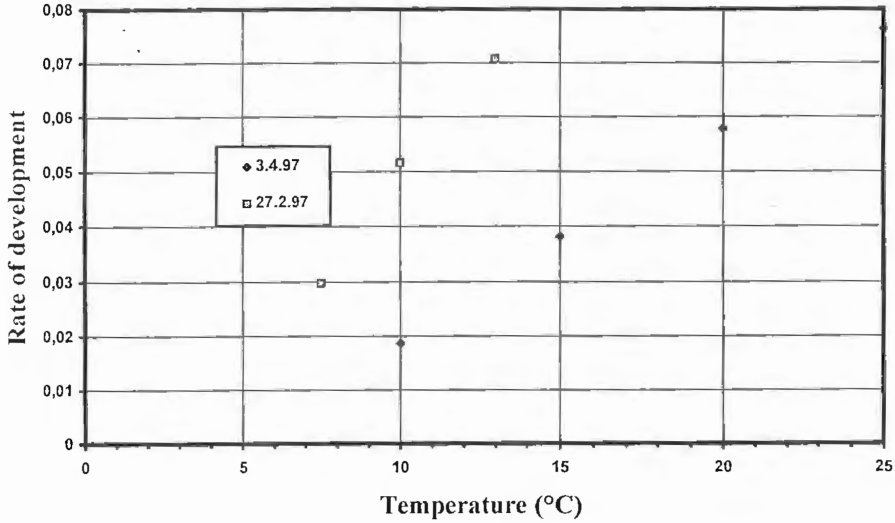

Figure 3. Post-diapause development of larvae of *Napomyza gymnostoma* collected from the field on 27 February and 3 April 1997.

not photoperiod (at least at this stage of development). These results agree well with our knowledge of the post-diapause development of many other insects (e.g. Tauber & Tauber, 1976).

The efficacy of several insecticides was tested in two field trials. The results are shown in Figure 4. It must be stressed that the mean efficacies of 71% for Phosalone (single values 75% and 66%) and of 74% for Heptenophos (single values 72% and 83%) were much higher values than those recorded for the rest of the compounds tested Nevertheless, these values are not very high. Many of the living larvae found after application of these compounds were in the lower parts of the leaves nearly at about ground-level or slightly below. In such positions, they are probably well-protected and, therefore, not affected by applications of insecticide.

For chemical control, farmers are advised to apply the above-mentioned insecticides when larvae are seen in the upper part of the leaves. To control this pest without applying insecticide, farmers are advised to grow leeks as far away as possible from chive. They are advised also to cover their leek crops with nets as soon as flies of the autumn generation emerge. When infested host plants are cleaned for market, many pupae are found on the plant remains. To prevent flies emerging from these pupae, plant residues should be buried deep in the soil. A warning service for *Napomyza gymnostoma* (Internet address: http://www.bfl.at) was established in Austria in 1997.

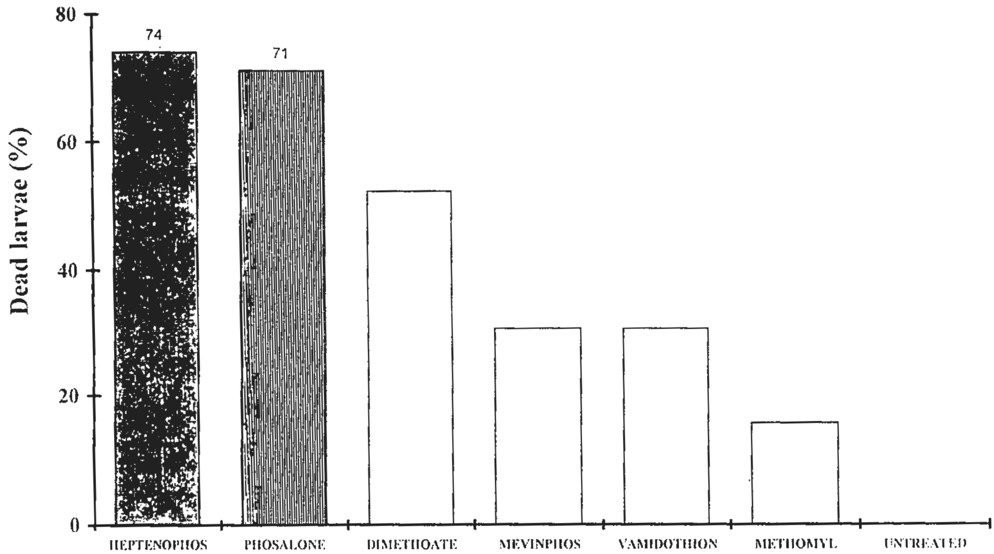

Figure 4. The relative efficacy of six insecticides in controlling field infestations of *Napomyza gymnostoma*.

Résumé

Biologie et lutte contre la mouche mineuse du poireau (*Napomyza gymnostoma* (Loew).

En 1994, un ravageur *Napomyza gymnostoma* (Loew) (Diptera : Agromyzidae), s'est installé de lui-même dans la partie Est de l'Autriche. Il est devenu maintenant un ravageur sérieux des poireaux (d'automne) et de la ciboulette. Les principaux dégâts sont les piqûres d'alimentation dans la ciboulette et la présence de pupes dans les feuilles de poireau, qui rendent les plantes non commercialisables. Les mines serpentent et sont souvent interrompues, elles sont localisées principalement à la base de la plante hôte. *N. gymnostoma* est bivoltine avec une génération au printemps et une à l'automne. En 1997, les pics d'émergences des adultes ont eu lieu le 28 avril et le 16 septembre. En été, il y a une longue période sans aucune émergence. Ainsi ce ravageurs semble estiver. A la température constante de 20°C, le développement (de l'oeuf à l'adulte) demande 73 jours à une photopériode de 6-10 heures et 112 à 120 jours, respectivement à une photopériode de 14 et 18 heures. Le développement de post diapause est induit par un changement de température mais non par la photopériode. Le plus bas seuil de température pour le développement est de 3,2°C et 5,4°C. La ciboulette est hautement favorable comme plante hôte car elle reste en végétation pendant une grande partie de l'année et ses feuilles sont utilisables aussi bien pour la génération de printemps que pour la génération d'été. Les expériences de lutte avec des produits insecticides montre que l'Heptenophos (330 g a.i./ha) et le Phosalone (420g a.i./ha) sont les insecticides les plus efficaces pour contrôler les larves de *N. gymnostoma*. La pratique courante est de réaliser des pulvérisations aussi longtemps qu'on trouve des larves dans la partie supérieure des feuilles. Pour lutter contre ce ravageur sans produit insecticides, les fermiers cultivent le poireau le plus loin possible de la ciboulette. On leur conseille également de couvrir la culture de poireau avec un filet pendant toute la période d'émergence des mouches de la génération d'automne, et d'arracher et d'enfouir profondément dans le sol les

plantes qui contiennent des pupes. Un service d'avertissement pour *N. gymnostoma* a été mis en place en Autriche en 1997

Acknowledgement

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Neem extracts for controlling caterpillars attacking cabbage

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Abstract: At the Plant Protection Centre in Norway, we have done a series of experiments to evaluate neem extracts (extracts from seeds of the neem tree, *Azadirachta indica*) for controlling lepidopteran pests of cabbage. Promising results were obtained in laboratory experiments in which neem extracts were tested against larvae of *Mamestra brassicae, Plutella xylostella, Pieris rapae* and *P. brassicae.* Further studies were done using cabbage moths produced in a laboratory culture. One study showed that in addition to possessing activity as an insect growth regulator (IGR), neem extracts have a repellent effect that can reduce oviposition. Antifeedant effects of neem on larvae were also demonstrated, as was systemic activity through water uptake by plants. When sprayed onto the plants, concentrations of azadirachtin (the most active ingredient in neem extracts) above 2ppm prevented larval development. Concentrations above 8ppm prevented plant damage. After being sprayed the plants were effectively protected from damage for 1-2 weeks.

Key words: Neem, *Azidiraclta indica, Mamestra brassicae, Plutella xylostella, Pieris rapae, P. brassicae*

Introduction

The neem tree is a subtropical plant which can thrive in marginal soils. Several chemicals in the seeds, especially azadirachtin, have antifeedant and toxic effects on herbivorous insects (e.g. Jacobson 1986). Over seventy years of research on the effects of neem extracts on almost 200 insect species have led to the production of several neem-based insecticides (Ketkar & Ketkar 1993). Despite this commercialization, research is still needed both to determine which pests can be controlled with neem and to develop practical treatment strategies. At the Plant Protection Centre of the Norwegian Crop Research Institute, we have investigated neem extracts for the control of several lepidopteran pests of cabbage. The species investigated are the key pest caterpillars of cabbage in Norway and other European countries (e.g. Collier *et al.* 1996).

Experimental Section

Insect cultures

The species investigated were the cabbage moth (*Mamestra brassicae*), the diamondback moth (*Plutella xylostella*), the large white butterfly (*Pieris brassicae*) and the small white butterfly (*Pieris [=Artogeia] rapae*). Eggs and larvae were collected from unsprayed plants in the field and reared in petri dishes using cabbage leaves as food. For the cabbage moth, cultures were established by following the methods of Fischer & Otto (1976) but using cabbage leaves instead of the artificial diet.

Neem extracts
We investigated two different neem extracts, Neem Azal-T (from Trifolio-M GmBh), and our own extract made from neem seed kernels. To make the extract, we ground the kernels to a powder using a coffee grinder and made a suspension in water at room temperature. After 24-hours, the suspension was strained through a cheesecloth, before being diluted for use. The extracts were applied using hand-sprayers, except in the experiment done to study the systemic movement of the neem within the plant. Unless stated otherwise, the solutions used of our extract contained approximately 0.05% a.i. (azadirachtin) and those of the Neem Azal-T approximately 0.01% a.i.

Several practical aspects of using neem extracts were investigated. For all of the species of caterpillars, we compared the effect of Neem Azal-T with our own extract. The cultures of cabbage moth provided enough larval material for other investigations. A dose-response test was conducted using Neem Azal-T after dipping cabbage plants. A separate experiment investigated the residual activity of Neem Azal-T after it had been applied topically to cabbage leaves. Both Neem Azal-T and our own extract were applied to the soil to study whether they could affect the larvae following systemic uptake by the plant. The repellent effect of Neem Azal-T against ovipositing cabbage moths was studied by presenting the females with sprayed and unsprayed plants.

Comparison of extracts
Cabbage plants were sprayed to run-off in the field with either water (control), Neem Azal-T or our own extract. Plants were sprayed in random order to minimize differences in plant quality that could arise from different locations in the field. After the plants had dried, samples of leaves were collected and were presented to larvae maintained in Petri dishes in the laboratory. The larvae were separated into the different species and instars. Leaves were replaced with fresh leaves from the original plants every second day for the small larvae and every day for the larvae older than the fourth instar. Records were taken of larval development, larval mortality and plant damage.

Diamondback moth larvae that were in the earliest instars (I-II) at the start of the experiment showed 100% mortality after 12 days when fed leaves treated with our extract. With Neem Azal-T mortality was 60% after 12 days and 91% after 22 days. Natural mortality in the control was 3% after 12 days and 32% after 22 days. Of the larvae that survived the Neem Azal-T treatment, the majority did not develop past the fourth instar. In the control treatment, the majority developed to adults. The damage recorded, on leaves treated with both neem extracts, was minimal.

Larvae of the large white butterfly were more susceptible to the neem extracts than diamondback larvae. For larvae of the large white butterfly, 100% mortality from both neem extracts was recorded in the tests using small larvae (instar II-III) after 8 days and large larvae (instar IV) after 8 days (own extract) and 10 days (Neem Azal-T).
The larvae in the neem treatments did not survive long enough to consume measurable amounts of plant material.

The results for the small white were similar to the large white, but the effect was a little slower. Our extract caused 100% mortality in small larvae after 10 days. Neem Azal-T caused 100% mortality after 14 days. Feeding ceased in the neem treatments after 8 and 10 days, respectively.

There was 100% mortality of small cabbage moth larvae (instar II) after 12 days from our neem extract and after 14 days from the Neem Azal-T extract. Feeding ceased after 10 and 12 days, respectively. With the fourth-instar larvae, both neem extracts produced 100% mortality after 12 days.

Oviposition repellent

Potted cabbage plants at the 6-8 leaf stage were sprayed with Neem Azal-T. Ten sprayed and ten unsprayed plants were placed into each of 3 large (2x2x2m) outdoor cages. The positions of the blocks of ID sprayed and 10 unsprayed plants placed into each cage were allocated at random. Flowering vegetation and a honey solution were placed at the centre of each cage. Five gravid cabbage moth females and 5 males were released into each cage. The females had been ovipositing for 1 day prior to release. The numbers of egg clusters and eggs were counted after 9 days.

The average number of egg clusters per plant was 0.9 for the neem treated plants and 2.2 for the control plants. The mean numbers of moth eggs recovered from the neem-treated and control plants were 64 and 144, respectively.

Systemic activity

Both Neem Azal-T and our extract were used to determine whether watering plants with neem solution would have any effect on caterpillars feeding on the plant foliage. Potted cabbage plants in the 8-10 leaf stage were watered once with 100 ml of our neem extract, Neem Azal-T or plain water. The plants were arranged in a randomized block design in a screenhouse. After 3 days, cabbage moth larvae (instar II) were caged on the plants with individual plants cages. Larval mortality, larval development and plant damage were recorded 20 days later.

Although there did not appear to be any phytotoxic effects from either of the neem treatments, the plants treated with our extract were darker green than those sprayed with Neem Azal-T or water. The Neem Azal-T extract and our extract produced 93% and 80% larval mortality, respectively. The control mortality was 7%. The larvae that survived in the neem treatments were small and weak (instar II-III), whereas those in the control treatment had developed to instar IV and were active. The control plants were skeletonized, whereas the neem-treated plants suffered only minimal damage.

Dose-response

A serial dilution was done to produce test solutions of Neem Azal-T that contained from 0 to 16 ppm a.i. (azadirachtin). Potted cabbage plants at the 8-10 leaf stage were then inverted and dipped into one of the test solutions for 1 minute. Following treatment, the plants were arranged in a randomized block in a screenhouse and allowed to dry for 3 hours. Cabbage moth larvae (instar II) were then caged individually onto the treated plants. Larval mortality, larval development and plant damage were recorded 16 days later.

Increasing concentrations gave increasing mortality. No concentration produced 100% mortality, nor was there any flattening of the response curve at the higher doses. Concentrations of 4 ppm a.i., or greater, killed more than 50% of the larvae. Concentrations of 2 ppm a.i., or greater prevented larvae from developing past instar II. Concentrations of 8 ppm a.i., or greater, gave good control.

Residual activity

Potted cabbage plants at the heading stage were sprayed with Neem Azal-T 3-weeks 2-weeks 1-week and 1-hour before cabbage moth larvae (instar II) were caged onto the plants. The test plants were arranged in a randomized block design and were kept outdoors so that the treatments could be exposed to sunlight and other natural weathering conditions. The larvae were allowed to feed on the plants for 11 days, after which larval mortality, larval development, and plant damage were recorded.

There were no significant differences in mortality between the larvae on the control and those added to the test plants 3-weeks after the neem was applied. However, the larvae in the neem treatment were under-developed, and less than 7% of them reached the fourth instar. In addition, there was significantly less damage in this treatment than in the control. Mortality was much higher when the spray was applied 1-hour, 1-week and 2-weeks before the larvae were added. All three treatments prevented larval development and plant damage.

Discussion

The results from all of the experiments showed that neem could be used to control caterpillar pests of cabbage crops. The present results confirm the findings of Karelina *et al.* (1992) who tested neem against the cabbage moth and the small white butterfly, and Mordue *et al.* (1993) who tested neem in field trials against diamond-back moth, cabbage moth and the small white butterfly. Our additional finding that neem deters females from laying on treated plants would be an added benefit if neem were to be included as part of an integrated control system.

The results indicate the effective dose needed to control caterpillars. We were able also to establish the length of time that an application remained effective during the time of year when the cabbage moth is normally active. Although formulated neem products may be needed to obtain approval from regulatory agencies, "home-made" extracts can be as effective as formulated ones.

Résumé

Extrait de neem pour lutter contre les attaques de chenilles sur chou

Au centre de Protection des Plantes en Norvège, nous avons fait une série d'expériences pour évaluer des extraits de neem (extraits de la graine de l'arbre neem, *Azadirachta indica*) pour contrôler les Lépidoptères ravageurs du chou. Des résultats prometteurs sont obtenus en laboratoire contre les larves de *Mamestra brassicae, Plutella xylostella, Pieris rapae* et *P. brassicae*. Plusieurs expériences ont été faites en utilisant des larves produites en laboratoire. Une étude montre que le neem possède en plus une activité de régulateur de croissance d'insecte (IGR), et que des extraits ont un effet répulsif qui peut réduire la ponte. Des effets antiapétant du neem sur les larves ont également été démontrés, à partir de l'activité systémique provenant de l'eau absorbée par la plante. Lorsque les pulvérisations sont faites sur la plante, les concentrations d'azadirachtin (le produit le plus actif des extraits de neem) jusqu'à 2 ppm empêchent le développement des larves. Les concentrations supérieures à 8 ppm empêchent les attaques des plantes. Une fois pulvérisées, les plantes sont efficacement protégées pendant 1- 2 semaines.

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Using imidacloprid as part of an integrated system for controlling the black bean aphid *Aphis fabae* Scop.

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Abstract: Field experiments on the effectiveness of imidacloprid in controlling the black bean aphid on broad bean were carried out at the Research Institute of Vegetable Crops in Skierniewice. The experiments were done using four replicates of each treatment in a randomised block design. Imidacloprid was applied as Gaucho 350 FS, which contains 35% of the active ingredient. The results of the experiments indicated that imidacloprid was highly effective for controlling the black bean aphid. Imidacloprid applied as a seed dressing, protected the broad bean plants throughout the whole season. In contract to overhead sprays, seed dressings do not kill natural parasitoids and predators.

Key words: Black bean aphid, *Aphis fabae,* imidacloprid

Introduction

The black bean aphid is one of the most important pests of broad bean in Poland. When infestations are heavy, this aphid can destroy up to 80% of the potential yield. The mass flight of black bean aphids to bean fields takes place usually towards the beginning of June.

To decrease the adverse effects associated with foliar sprays of insecticide, imidacloprid was applied as the seed dressing.

Experiments on the efficiency of imidacloprid for controlling aphids have been done by several authors, e.g. Hildenhagen *et al.*, 1993; Dewar, 1992; Narkiewicz-Jodko, 1995 & 1996; Nauen & Elbert, 1994; Tatchell 1992; Troltzch *et al.*, 1994; Stein-Denecke *et al.*, 1992.

Materials and methods

In 1993-1996, field experiments were carried out on the effectiveness of Gaucho 350 FS (imidacloprid) in controlling black bean aphid. The experiments included four replicates using a randomised block design. Gaucho 350 FS was used as a seed dressing.

To determine the efficiency of the insecticides used, the numbers of live aphids were recorded on treated and untreated plots, sampling 5 plants at different times after treatments.

Results

The results of the experiments are shown in Tables 1-4.

As can be seen in Table 1, Gaucho 350 FS at the rate of 5 ml/kg of seeds, performed extremely well and killed over 99% of the aphids.

The results obtained in 1993 were confirmed in 1994, when Gaucho 350 FS used at the same rate protected the broad beans during the entire season and killed 100% of aphids (Table 2). Good control was obtained also with Gaucho 350 FS in 1995 (Table 3), as no aphids were recorded during the entire season. Experiment done in 1996 confirmed the results of the three previous years (Table 4).

Table 1. The effectiveness of imidacloprid (Gaucho 350 FS) and carbosulfan (Marshal 250 DS) in controlling black bean aphid (*Aphis fabae* Scop.) on broad bean plants, cv. Windsor Bialy, Skierniewice, 1993.

	Mean no. of living aphids/plant			
Observation dates	imidacloprid Gaucho 350 FS 3 ml/kg	Imidacloprid Gaucho 350 FS 5ml/kg	carbosulfan Marshal 250 DS 10g/kg	Control
June 28	0	0	0	0
July 1	2	0	0	0
July 5	3	0	0	0
July 9	2	1	4	24
July 16	4	0	0	52
July 22	6	0	0	60
July 29	1	0	0	33

Table 2. The effectiveness of imidacloprid (Gaucho 350 FS) and triazamate (Aztec 140 EW) in controlling black bean aphid (*Aphis fabae* Scop.) on broad bean plants, cv. Hangdown Bialy, Skierniewice, 1994.

	Mean no. of living aphids/plant			
Observation dates	Gaucho 350 FS 5 ml/kg	Aztec 140 EW 0.3 l/ha	Control	L.S.D. (α=0.05)
June 7	0	82	101	25
June 8	0	0	107	16
June 10	0	0	172	68
June 15	0	0	428	
June 16	0	0	440	43
June 20	0	0	708	84
June 23	0	0	740	262
July 1	0	3	375	225
July 2	0	0	335	193
July 4	0	0	180	77
July 8	0	0	121	70

Table 3. The effectiveness of imidacloprid (Gaucho 350 FS) and carbosulfan (Marshal 250 DS) in controlling black bean aphid (*Aphis fabae* Scop.) on broad bean plants, cv. Bartom, Skierniewice, 1995.

	Mean no. of living aphids/plant			
Observation dates	Gaucho 350 FS 5 ml/kg	Marshal 250 DS 10 g/kg	Control	L.S.D. (α=0.05)
June 14	0	5	149	414
June 21	0	19	345	1,115
June 28	0	27	501	
July 6	6	57	887	

Table 4. the effectiveness of imidacloprid (Gaucho 350 FS) and carbosulfan (Marshal 250 DS) in controlling black bean aphid (*Aphis fabae* Scop.) on broad bean plants, cv. Bartom, Skierniewice, 1996.

	Mean no. of living aphids/plant			
Observation dates	Gaucho 350 FS 5 ml/kg	Marshal 250 DS 10 g/kg	Control	L.S.D. (α=0.05)
June 3	0	36	67	
June 4	0	37	69	23
June 7	0	58	120	26
June 10	0	70	148	37
June 18	0	88	194	90
June 25	1	103	225	139
July 2	0	116	425	290

Discussion

The results indicate that imidacloprid is highly effective in controlling the black bean aphid. When applied as a seed dressing imidacloprid protected broad bean crops throughout the entire growing season. In contrast to insecticide sprays, seed dressing do not kill natural parasitoids and predators. Hence imidacloprid is a good candidate insecticide for inclusion in integrated pest management systems aimed at controlling the black bean aphid.

Résumé

Utilisation de l'imidacloprid comme partie d'un système intégrée de lutte contre le puceron noir de la fève *Aphis fabae* Scop.

Des expérimentations aux champs ont été réalisés pour tester l'efficacité de l'imidacloprid sur le puceron noir de la fève sur haricot à l'Institut de recherches en cultures légumières de Skierniewice. Les expériences sont faites en réalisant quatre répétitions pour chaque traitement en blocs randomisés. L'imidacloprid a été utilisé sous la forme de gaucho 350 FS qui contient 35% de matière active. Les résultats montrent que l'imidacloprid est hautement efficace pour lutter contre le puceron noir de la fève. Le produit, appliqué en traitement de semence, protège le haricot pendant toute la saison. Au contraire des pulvérisations, les traitements de semence ne tuent pas les parasitoïdes et les prédateurs.

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Pests of winter radish (*Raphanus sativus* L.) and their control

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Abstract: The pest insect species found on winter radish plants in Poland during 1996 and 1997 were: *Delia radicum* L., *Ceutorrhynchus* spp., *C. pleurostigma* Marsh., *Phyllotreta nemorum L. and P. atra* F. The relative importance of each of these species was recorded. Plant covers and seed treatments were tested for their effectiveness in reducing damage by the cabbage root fly, *Delia radicum* L. and flea beetles, *Phyllotreta spp.* on plants of winter radish. The three covers tested were polythene nets that had a mesh of 1 x 1 mm or 1 x 1.5 mm or non-woven polypropylene fleece. The nets gave good pest control on all plots. The non-woven fleece did not provide effective control against *Delia radicum* but gave good protection against *Phyllotreta spp.* Insecticides were generally less effective in controlling both pests.

Key words: *Raphanus sativus, Delia radicum, Phyllotreta nemorum, P. atra*

Introduction

Crops of winter radish are often damaged severely in Poland by the cabbage root fly, *Delia radicum* and by flea beetles, *Phyllotreta nemorum* and *P. atra*. At present, insecticides are used to reduce such damage. To obtain effective control, insecticides have to be applied frequently, and this often proves difficult for crops that remain in the ground for only short periods. This paper describes how polythene net covers can be used instead of insecticides to control both of these pests.

Materials and methods

In 1996 and 1997, experiments were done at Skierniewice to record the pest species found on winter radish and to estimate the efficiency of plant covers in preventing damage by the cabbage root fly, *Delia radicum*, and flea beetles, *Phyllotreta spp.* on plants of winter radish.

Trial 1 – Winter radish cv. Agata (1996)

The following treatments were used:

1. Plants covered with polythene net (1 x 1 mm mesh) until harvest
2. Plants covered with polythene net (1 x 1.5 mm mesh) until harvest
3. Plant covered with a non-woven polypropylene fleece until harvest
4. Seed treated with teflubenzuron (90 ml/kg)
5. "Control" = untreated plants.

In 1996, the plots of winter radish were drilled on 9 May and covered later the same day. Each plot measured 3.0 x 1.5 m and the five treatments were replicated four times in a randomised block design. To determine the efficiency of the treatments, 100 plants were sampled at random from each plot. The numbers of plants damaged by the cabbage root fly were recorded.

Trial 2 – Winter radish cv. Agata (1997)
The following treatments were used:

1. Plants covered with polythene net (1 x 1 mm mesh) until harvest
2. Plants covered with polythene net (1 x 1.5 mm mesh) until harvest
3. Plants covered with a non-woven polypropylene fleece until harvest
4. Seed treated with teflubenzuron (90 ml/kg)
5. Seed treated with furathiocarb (70 ml/kg)
6. Seed treated with imidacloprid (70 ml/kg)
7. "Control" = untreated plants.

In 1997, the winter radish were drilled on 29 April and covered later the same day. Each plot measured 4.5 m x 1.2 m and the seven treatments were replicated four times in a randomised block design. To determine the efficiency of the treatments in controlling the cabbage root fly, 200 plants were sampled at random from each plot.

The numbers of plants damaged by the cabbage root fly and flea beetles were recorded from each plot to determine the relative efficiency of the various treatments.

Results

Five pest insect species were recorded on winter radish plants. The most numerous were the cabbage root fly, *Delia radicum* L. and the flea beetle species, *Phyllotreta nemorum* L. (Table 1).

Both types of net (1 x 1 mm and 1 x 1.5 mm mesh) gave satisfactory control of *D. radicum*. The non-woven polypropylene fleece was as effective as the nets in controlling the cabbage root fly in 1996 but not in 1997. Although the seed treatments were not as effective as the polythene covers (Table 2), furathiocarb was the most effective insecticide tested (Table 3).

Plants covered with both types of nets and non-woven polypropylene fleece gave good control of *Phyllotreta* spp., as only about 5–9% of the plants were damaged by flea beetles. Although the imidacloprid seed treatment gave satisfactory flea beetle control, the other seed treatments were not effective (Table 4).

Table 1. The relative importance of pest insect species found expressed as percentages.

	Percentage presence	
SPECIES	1996	1997
Delia radicum L.	100	100
Phyllotreta nemorum L.	73	82
Phyllotreta atra F.	27	18
Ceutorrhynchus spp.	16	24
Ceutorrhynchus pleurostigma Marsh	2	1

Table 2. Effect of crop covers and insecticides in protecting winter radish from damage by *Delia radicum* L. in Skierniewice in 1996.

TREATMENTS	Mean percentage of healthy plants	Mean percentage of injured plants	Marketable crop kg/plot
Plants covered with polythene (1 x 1 mm mesh)	86 a	14 a	41 a
Plants covered with polythene (1 x 1.5 mm mesh)	87 a	13 a	43 a
Plants covered with non-woven polypropylene fleece	71 b	29 b	32 b
Seeds treated with teflubenzuron (90 ml/kg)	68 b	32 b	28 b
Control – untreated plants	27 c	73 c	9 c

Means followed by the same letter do not differ (P=0.05)

Table 3. Effect of crop covers and insecticides in protecting winter radish from damage by *Delia radicum* L. in Skierniewice in 1997.

TREATMENTS	Mean percentage of healthy plants	Mean percentage of injured plants	Marketable crop kg/plot
Plants covered with polythene (1 x 1 mm mesh)	80 a	20 a	38 a
Plants covered with polythene (1 x 1.5 mm mesh)	82 a	18 a	39 a
Plants covered with non-woven polypropylene fleece	64 c	36 c	28 b
Seeds treated with teflubenzuron (90 ml/kg	62 c	38 c	28 b
Seeds treated with furathiocarb (70 ml/kg)	76 b	24 b	31 b
Seeds treated with imidacloprid (70 ml/kg)	61 c	39 c	26 b
Control – untreated plants	30 d	70 d	12 c

Means followed by the same letter do not differ (P=0.05)

Table 4. Effect of crop covers and insecticides in protecting winter radish from damage by *Phylotreta spp.* in Skierniewice in 1997.

TREATMENTS	Mean percentage of injured plants
Plants covered with polythene (1 x 1 mm mesh)	5 a
Plants covered with polythene (1 x 1.5 mm mesh)	9 a
Plants covered with non-woven polypropylene fleece	6 a
Seeds treated with teflubenzuron (90 ml/kg)	88 d
Seeds treated with furathiocarb (70 ml/kg)	35 c
Seeds treated with imidacloprid (70 ml/kg)	15 b
Control – untreated plants	93 d

Means followed by the same letter do not differ (P=0.05)

Discussion

Delia radicum caused severe losses in the marketable yield of winter radish. Applying insecticides did not give sufficient control of this pest. Protective nets were more effective than insecticides in controlling the cabbage root on winter radish. This confirms the results of earlier work by Häseli & Konrad, 1987; Richter, Krauthausen & Ziegler, 1989; Merz, 1989; and Ester *et al.,* 1994. Although covering crop with nets is more expensive than using insecticides, nets are an effective alternative to insecticides for preventing damage by the cabbage root fly and flea beetles on crops of winter radish.

Résumé

Les ravageurs du radis d'hiver (*Raphanus sativus* L.) et leur contrôle

Les insectes ravageurs trouvés sur les plantes de radis en Pologne en 1996 et 1997 sont : *Delia radicum* L., *Ceutorrhynchus spp., C. pleurostigma* Marsch, *Phyllotreta nemorum* L. et *P. atra* F. L'importance relative de chacune des espèces a été notée. La couverture des plantes et les traitements de semences sont testés pour leur efficacité en réduisant les dégâts de la mouche du chou *D. radicum* et des altises *Phyllotreta spp* sur les cultures de radis d'hiver. Les trois types de couverture testées sont un filet de polythène dont la maille était de 1x1mm, de 1x1.5mm et un intissé. Les filets donnent une bonne protection contre les ravageurs dans toutes les parcelles. Le polythène intissé n'assure pas une bonne protection contre *D. radicum* mais est efficace contre les altises. Les insecticides sont généralement moins efficaces pour contrôler les deux ravageurs.

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The occurrence and control of *Pemphigus phenax*, an aphid that infests the roots of carrots

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Abstract: In Poland, the wingless aphids of *P.phenax* begin to infest carrot roots from about the end of July. When such infestations are left untreated, large numbers of aphids can be found on the roots of the carrots at harvest. Four methods were investigated for controlling root aphid infestations in carrot crops. The most effective was to apply the insecticide imidacloprid either as a seed treatment (350 FS) or as a spray (200 SL) applied to kill the wingless aphids on the roots of the carrot plants.

Key words: Carrots, *Pemphigus phenax, imidacloprid,* seed treatments

Introduction

In addition to the carrot fly (*Psila rosae*), the root aphid *Pemphigus phenax*, is the other major pest of carrot crops in Poland. This aphid has two host plants. Each year, the aphid completes three to six generations on its overwintering host the poplar followed by six to nine summer generations on the roots of carrot plants (Goszczyński, 1976). Aphids feeding on carrots not only reduce quality but can also cause considerable losses in yield (Stroyan, 1964; Herfs, 1973; Goszczyński, Cichocka, 1986).

The aim of this research was to develop a more environmentally-friendly method of control than the one used currently, which consists of spraying the carrot crop three times during the period when the aphids are migrating from the poplar trees to the carrot fields.

Materials and methods

The experiments were done in 1995-1997 in two areas of Poland (Skierniewice & Boguslawice) separated by about 250 km. The carrots were grown in a sandy soil in Skierniewice and in a loess soil in Boguslawice. The numbers of carrot roots infested by *P. phenax* were assessed once each week. At three positions in an 800 sq. m field, the carrots were lifted from a 1 m length of row so that the numbers of infested roots could be recorded.

In the field experiments, each treatment was replicated 4-times in a randomized block. The carrots were grown in rows spaced 40 cm apart in Skierniewice, and in 62.5 cm wide beds in Boguslawice. The seed was drilled in the third week of April and all seed was treated with the fungicide mixture/kg of seeds: Apron DS 35 (1g) + Funaben T (3g).

The four methods of root aphid control tested were:

1. seed treatment
2. drenching the rows of carrots in June with a rate equivalent to 1200 l of solution/ha, at the time when the first aphids started to fly from the poplar trees into the carrot fields
3. three insecticide sprays applied in June at a rate equivalent to 600 l of water/ha, at the time when the aphids were migrating from the poplar trees to the carrot fields
4. two insecticide sprays applied in August at a rate equivalent to 600 l of water/ha, to kill specifically the aphids feeding on the carrot roots.

The efficacy of each method was estimated by recording both the numbers of roots infested by *P. phenax* at harvest, and crop yield. Statistical analysis were done using the Newman-Keuls test, $\alpha = 0.05$.

Results and discussion

The first aphid-infested carrot roots were found during the last week of July (Table 1). The number of infested roots then increased gradually until the middle of October, after which the numbers of aphids declined as the weather became colder and temperatures fell below 10°C. In August and September, between 25–60 aphids were found per root. By the end of October the number had declined to less than 8/root and, after the first frost (5 November 1997), no living aphids were found. Goszczyński and Cichocka (1986) recorded considerable losses in yield when the mean numbers of aphids exceeded 46/root.

Table 1. Percentage of carrot roots infested by the root aphid *Pemphigus phenax*, during the growing season. Assessments made at Skierniewice and Bogusławice during 1996 and 1997.

Date of observation		Mean percent of infested roots			
		Skierniewice 1996	Bogusławice 1996	Skierniewice 1997	Bogusławice 1997
July	25	0	0	0	2
August	01	0	0	0	2
	10	0	0	0	5
	20	9	0	4	8
September	01	12	22	12	6
	10	19	23	23	13
	20	22	29	33	10
October	01	17	31	66	13
	10	20	43	62	25
	20	Harvest	Harvest	65	32
November	01			61	31
	05			60 *	Harvest

*Dead aphids: temperature on the soil surface = -12°C.

Of the 4 methods tested, the most effective appeared to be both the prophylactic seed treatment and the spraying of plants at the beginning of root infestation by the wingless aphids.

Of the seed treatments tested, imidacloprid proved to be the most effective. Less infested roots were found when the seeds were treated with imidacloprid than with carbosulfan, furathiocarb or acetamoprid (Table 2 & 3). Imidacloprid gave much better control when applied at 70cc/kg of seed than at 50cc/kg of seed (Table 2). Applying drenches to the carrot rows, or applying 3-sprays during the period of aphid migration, gave much poorer control (Table 2 & 3). In contrast, changing the timing of the treatments from June to August, and reducing the number of treatments applied, gave much better control. The optimum effect from the treatments made in August, was achieved by spraying the plants twice during the first two weeks of August, irrespective of the insecticide used (Table 3).

Table 2. Comparison of various insecticides, applied as seed treatments, drenches or sprays, for controlling infestations of the root aphid, *Pemphigus phenax*, in carrot crops. Field experiments done at Skierniewice during 1995 and 1996.

Application method	Compound	Amount of insecticide	Application period	Infested roots 10 sq.m.	Total yield 10 sq.m.
Experiment 1, 1995					
Seed treatment	imidacloprid, 350 FS	50 cc/kg	before sowing	24 ab	52 a
Seed treatment	imidacloprid, 350 FS	70 cc/kg	before sowing	8 a	50 ab
Seed treatment	carbosulfan, 250 DS	70 g/kg	before sowing	54 c	50 ab
Spray	pyrimicarbe, 50 DG	150 g ai/ha	3 times: June 21 & 30, July 7	62 c	52 a
Spray	oxydemeto-methyl, 250 EC	75 cc ai/ha	3 times: June 21 & 30, July 7	44 bc	52 a
Drench	oxydemeto-methyl 250 EC	150 cc ai/ha	1 time: June 21	55 c	47 ab
Drench	dimethoate, 400 EC	480 cc ai/ha	1 time: June 21	50 c	44 ab
-	Check	-	-	104 d	41 b
Experiment 2, 1995					
Seed treatment	imidacloprid, 350 FS	70 cc/kg	before sowing	22 a	76 a
Seed treatment	carbosulfan, 250 DS	70 g/kg	before sowing	201 c	57 b
Drench	dimethoate, 400 EC	240 cc ai/ha	1 time: June 21	142 b	60 b
Drench	chloropyriphos-methyl, 500 EC	300 cc ai/ha	1 time: June 21	120 b	62 b
Spray	pyrimicarbe, 50 DG	150 g ai/ha	3 times: June 21 & 30, July 7	123 b	57 b
-	Check	-	-	263 d	51 b
Experiment 3, 1996					
Seed treatment	imidacloprid, 350 FS	50 cc/kg	before sowing	8 a	92 n.s.
Seed treatment	imidacloprid	70 cc/kg	before sowing	4 a	93
Seed treatment	furathiocarb, 400 CS	70 cc/kg	before sowing	38 b	96
-	Check	-	-	99 c	87
			The Newman-Keuls, $\alpha = 0.05$.		

All of the seed used was treated with fungicides: Apron 35 SD (1 g/kg) + Funaben (3 g/kg of seed). n.s. = not significant.

Table 3. Comparison of various insecticides, applied as seed treatments or sprays, for controlling infestations of the root aphid, *Pemphigus phenax*, in carrot crops. Field experiments done at Skierniewice and Bogusławice during 1997.

Application method	Compound	Amount of insecticide	Application period	Infested roots 10 sq.m.	Total yield 10 sq. m.
Experiment 1, Skierniewice 1997					
Seed treatment	imidacloprid, 600 FS	29 cc/kg	before sowing	6 a	74 n.s.
Seed treatment	acetamiprid, 70 WP	25 g/kg	before sowing	84 c	63
Spray	oxydemeto-methyl, 250 + beta-cyfluthrin, 8	95 cc ai/ha	1 time: August 4	55 b	71
Spray	oxydemeto-methyl, 250 + beta-cyfluthrin, 8	95 cc ai/ha	2 times: August 4 & 14	18 a	76
Spray	pyrimicarbe, 25 WG	150 g ai/ha	2 times: August 4 & 14	28 a	76
Spray	imidacloprid, 200 SL	84 cc ai/ha	2 times: August 14 & 28	14 a	74
-	Check	-	-	144 d	64
Experiment 2, Skierniewice 1997					
Seed treatment	imidacloprid, 600 FS	29 cc/kg	before sowing	9 a	73 ab
Seed treatment	acetamiprid, 70 WP	25 g/kg	before sowing	170 c	64 bc
Spray	imidacloprid, 200 SL	120 cc ai/ha	1 time: August 4	43 ab	72 ab
Spray	imidacloprid, 200 SL	120 cc ai/ha	1 time: August 14	40 ab	74 ab
Spray	imidacloprid, 200 SL	120 cc ai/ha	1 time: August 28	81 b	71 ab
Spray	imidacloprid, 200 SL	120 cc ai/ha	2 times: August 4 & 14	9 a	77 a
-	Check	-	-	339 d	59 c
Experiment 3, Bogusławice 1997					
Seed treatment	imidacloprid, 600 FS	29 cc/kg	before sowing	7 b	62 n.s.
Seed treatment	acetamiprid, 70 WP	25 cc/kg	before sowing	11 bc	58
Spray	imidacloprid, 200 SL	120 cc ai/ha	1 time: August 15	12 bc	62
Spray	imidacloprid, 200 SL	120 cc ai/ha	2 times: August 1 & 15	4 a	63
Spray	pyrimicarbe, 50 DG	150 cc ai/ha	3 times: June 20 & 30, July 7	15 c	58
-	Check	-	-	29 d	59
				The Newman - Keuls test, $\alpha = 0.05$	

All of the seed used was treated with fungicides: Apron 35 SD (1 g/kg) + Funaben (3 g/kg of seed). n.s. = not significant.

Conclusions

1. *Pemphigus phenax* began to migrate from poplar trees to carrot crops during the last week of July. Aphid numbers increased until the middle of October, and then declined, as the weather became colder.
2. Treating the seed with imidacloprid, or spraying the carrot plants twice with imidacloprid during the main period of aphid infestation, were both more effective than the currently used practice of spraying the carrot plants three times during the start of the period of aphid migration.
3. The most effective control was achieved by treating seeds with imidacloprid at the rate of 17.5 – 24.5 cc ai/kg of seeds, or by applying two sprays, each equivalent to 120 cc ai/ha, during the main period of aphid infestation.

Résumé

Les périodes de présence et la lutte contre *Pemphigus phenax*, un puceron Ravageurs des racines de carotte

En Pologne, les pucerons aptères de *P. phenax* commencent à infester les racines de carotte vers la fin du mois de juillet. Quand de telles cultures ne sont pas traitées, un grand nombre de pucerons peut être trouvé sur les racines à la récolte. Quatre méthodes sont testées pour lutter contre les infestations du puceron de la racine en culture de carotte. La plus efficace est l'application de l'insecticide imidacloprid soit en traitement de semence (350 SF) soit en pulvérisation (200SL).

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Monitoring and control of *Thrips tabaci* Lind. with furathiocarb in leek fields

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Abstract: In Belgium, attacks by thrips (*Thrips tabaci* Lind.), and to a lesser extent by the leek moth (*Acroleopsis assectella* Z.), cause high losses in crop quality and sometimes in plant weight. Thrips are particularly difficult to control. Despite commercial leek crops being sprayed intensively during the whole season, thrips control often fails, and the percentage of unmarketable plants becomes too high, especially in autumn and early-winter leek crops. Since 1996, furathiocarb has been recommended for controlling thrips in leek crops but has been restricted to only two post-planting sprays. A field experiment was carried out during 1996 and 1997 to determine a spray threshold, based on the number of thrips/leek. The flight activity of thrips was monitored in the field with blue sticky traps, to give information on the risk of infestation from outside the field. The appropriate threshold seems to be near to 10 larvae per leek plant. To produce leek of the highest quality, a second spray needs to be applied three weeks later. The flight period of the thrips extended from the end of July to 20-25 August. Smaller numbers of *T. tabaci* were caught before and after this period. Peak flight activity occurred on 21 August 1996 and on 17 August 1997.

Key words: *Thrips tabaci, Acroleopsis assectella*, insecticides

Introduction

In Belgium, leek, *Allium porrum* L is a major field vegetable crop. The onion thrips, *Thrips tabaci* Lind., is the most important pest of leek crops. Large populations of thrips may develop on leeks during July and August and cause silvery spots or stripes on the leaves, which make the crop unmarketable.

Growers currently spray intensively with insecticides during the summer months, because of insufficient knowledge on integrated pest management. However, repeated treatment with registered insecticides (endosulfan, parathion, deltamethrin, cyhalothrin, permethrin, propoxur, formetanat or methiocarb) is not an efficient way of controlling thrips (Hommes et al., 1994). Based on the positive results obtained in earlier experiments (Freuler & Benz., 1988; Van de Steene, 1996), furathiocarb has been recommended in Belgium since 1996 for controlling thrips in leek crops, but restricted to only two post-planting sprays. For this reason a field experiment was done during 1996 and 1997 to develop a more robust method, based on a spray threshold.

Based on the positive results obtained in France (Villeneuve, 1995) and in Austria (Kahrer, 1994), blue sticky traps were used to monitor flight activity of thrips in the experimental fields.

Materials and methods

The experiments were done at the Vegetable Research Station at Sint-Katelijne-Waver during 1996 and 1997. Leek plants, grown in a plant nursery and protected with "Lanet" gauze (polyethylene with a mesh of 0.17 x 0.37 mm), were transplanted into the experimental plots. The plants were spaced 12 cm apart within the row and 40 cm apart between the rows. The sampling details and the experimental data for the two experiments are shown in Table 1.

Table 1. Cultural and sampling details for the field experiments done in 1996 and 1997.

Details of the 2 experiments	1996	1997
Locality	Sint-Katelijne-Waver	Sint-Katelijne-Waver
Crop	autumn leek	autumn leek
Cultivar	Arkansas	Arkansas
Sowing date	3 April	26 March
Planting date	3 July	26 June
No. of treatments	6	4
No. of replications	3	3
No. of plant/plot	240	200
Total No. of plants	5,040	3,000
Assessment of thrips	weekly, from 10 July to 30 October	weekly, from 9 July to 15 October
No. of plants assessed/plot	5	5
Quality assessment	23 September	30 September
Yield assessment	12 November	14 November

Furathiocarb (400 g a.i./ha) was sprayed twice in each experimental field, except in one plot during 1996, at two different times to control thrips. The date of the treatments is shown in Table 2.

Table 2. Treatments applied to the field experiments done in 1996 and 1997.

	1996	1997
1	untreated (no insecticide)	untreated (no insecticide)
2	furathiocarb on 31 July & 14 August	furathiocarb on 6 & 27 August
3	furathiocarb on 31 July & 27 August	furathiocarb on 13 August & 3 September
4	furathiocarb on 31 July, 21 August & 11 September	furathiocarb on 20 August & 10 September
5	furathiocarb on 7 August & 28 August	furathiocarb on 27 August & 17 September
6	furathiocarb on 7 August & 4 September	
7	furathiocarb on 21 August & 4 September	

Five leek plants, distributed regularly over the plot, were sampled each week. The heart and the leaves of each plant were inspected carefully in the laboratory for thrips larvae. Aerial counts of adults were recorded weekly on 8 x 15 cm light-blue sticky traps. Three traps were used and the individual traps were spaced at least 20 m apart in the field. The traps were supported 10 cm above the crop and their height was raised as the leeks grew.

Results and discussion

Flight activity of thrips

Data from sticky traps indicated that the main flight period was from the end of July to the end of August in 1996 and from 10 August to the end of August in 1997. Before and after this period, smaller numbers of thrips were caught (Figure 1). The numbers of adults caught during the peak of flight activity were similar for the two years and reached about 200 thrips/trap/week. The period when high numbers of thrips were caught lasted for about a week in both 1996 and 1997.

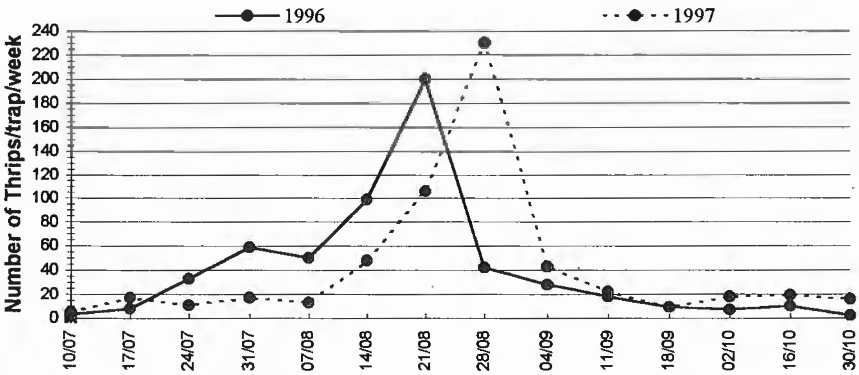

Figure 1. Numbers of *Thrips tabaci* collected from blue sticky traps placed in leek fields at Sint-Katelijne-Waver during 1996 and 1997.

Population of thrips on leek plants

Small numbers of thrips larvae were found on the leek plants sampled during July (Table 3). Large numbers of thrips were present from the end of August and this corresponded to the period of intense flight activity. Following this flight, the development of the thrips population on the leek plants (Figure 2) was similar in both years. Eight days after the increase in the number of the thrips caught on the traps, the number of thrips larvae increased on the leek plants (Figure 2).

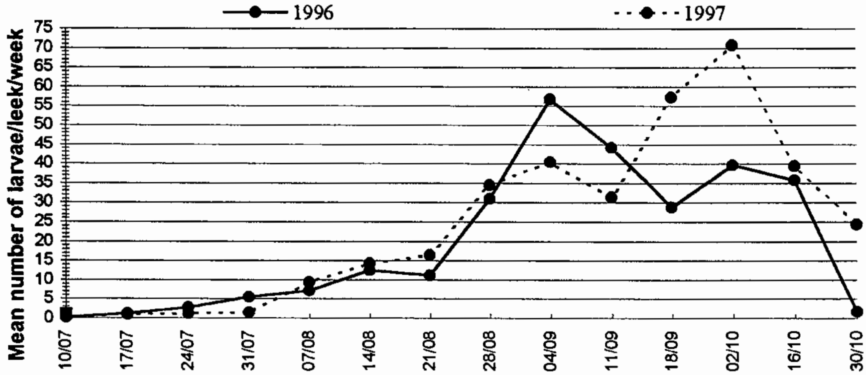

Figure 2. Numbers of thrips larvae collected from untreated leek fields at Sint-Katelijne-Waver during 1996 and 1997.

Control of thrips with furathiocarb

During 1996, furathiocarb was applied at a spray threshold of 5.5 thrips/leek on three fields; at a spray threshold of 7.1 thrips/leek on two fields; and at a spray threshold of 11.1 thrips/leek on one field (Table 3). The treatments markedly affected the infestation levels of thrips after eight days. A second spray was applied in August, two-, three-, or 4-weeks after the first spray. In the treated fields, the number of thrips did not exceed 5-6 during the rest of the season.

During 1997, the time between the first and second treatment in each field was three weeks. Treatments applied, at a spray threshold of 9.3 or 14.3 thrips larvae/leek on 6 and 13 August respectively and repeated three weeks later proved extremely effective. In contrast, a spray applied on 20 August at a spray threshold of 16.4 thrips or higher, and repeated after three weeks, was less effective against thrips larvae. In this situation, more than 5 larvae/leek were recorded one week after the treatments had been applied.

Damage by thrips and yield

At the end of the season, sixty plants from each treatment and sixty untreated leek plants were checked individually for damage, for marketability and for weight (Table 4). Damage by thrips was graded on a scale of 1 to 9, in which 1 = clean (no damage, quality extra; 3 = slight (quality A_1); 5 = moderate (quality B_1); 7 = severe (quality 2) and 9 = very severe. Applying the first spay after mid-August was too late, as by this time most of the plants were seriously damaged with silvery spots and/or stripes and were unmarketable. The data collected during 1996 and 1997 were similar. In the unsprayed fields, more than 90% of the leek plants were not marketable.

Table 3. Average numbers of thrips larvae recorded from unsprayed leek plants and from plots sprayed with furathiocarb.

1996 Spraying on \ Date	10/07	17/07	24/07	31/07	07/08	14/08	21/08	28/08	04/09	11/09	18/09	02/10	16/10	30/10
31/07 & 14/08					0.3	0.1	0.1	0.2	2.9	5.9	6.1	3.9	4.0	0.8
31/07 & 28/08							4.4	6.5	0.4	1.2	1.4	2.7	5.5	1.3
31/07, 21/08 & 11/09							5.7	0.4	1.3	1.8	0.1	0.4	0.6	0.1
07/08 & 04/09						0.3	0.1	5.9	5.4	0.2	1.4	0.5	1.6	0.2
07/08 & 28/08									0.2	0.3	1.1	1.2	3.3	0.3
21/08 & 04/09								6.1		0.4	0.6			
untreated	0.1	1.2	2.7	5.5	7.1	12.5	11.1	30.9	56.8	44.2	28.7	39.6	35.7	1.7
1997 Spraying on \ Date	**09/07**	**16/07**	**23/07**	**30/07**	**06/08**	**13/08**	**20/08**	**27/08**	**03/09**	**10/09**	**17/09**	**24/09**	**01/10**	**15/10**
06/08 & 27/08						0.6	1.1	1.4	0.1	0.6	1.5	1.3	2.0	1.9
13/08 & 03/09							1.0	1.9	3.7	1.5	1.4	9.6	11.9	4.0
20/08 & 10/09								6.2	29.0	7.7	4.5	8.1	13.0	9.8
27/08 & 17/09									8.5	5.3	9.0	5.7	4.8	4.1
untreated	0.2	0.9	1.1	1.4	9.3	14.3	16.4	34.5	40.4	31.4	57.3	70.7	39.4	24.4

Table 4. The grades of damage, mean plant weight and the percentage of marketable plants.

Year	Furathiocarb sprayed on	No. of plants with the scale index					% plants marketable showing crop loss due to thrips	Mean plant weight
		1	3	5	7	9		
1996	31/7, 14/8	37	23				100.0	243
	31/7, 28/8	42	18				100.0	245
	31/7, 21/8, 4/9	41	18	1			100.0	265
	7/8, 28/8	51	9				100.0	231
	7/8, 4/9	39	19	2			100.0	276
	21/8, 4/9	9	33	18			71.7	225
	untreated		3	21	34	3	13.3	248
1997	6/8, 27/8	45	15				100.0	304
	13/8, 3/9	9	43	8			91.7	285
	20/8, 10/9		3	52	5		11.7	320
	27/8, 17/9		4	43	10	3	6.6	244
	untreated				54	6	0.0	250

Conclusion

Furathiocarb (400 g a.i./ha) is very effective in controlling *Thrips tabaci* Lind infestations in leek crops. To produce high quality leeks, the first spray should be applied when there are 10 thrips (larvae)/leek plant followed by a second spray three weeks later. The flight period of thrips extended from the end of July until 20-25 August. Maximum flight activity occurred between 15-28 August.

Acknowledgement

I thank the Ministry of Middle Classes and Agriculture for supporting this research project.

Résumé

Activité de vol de *Thrips tabaci* Lind et lutte avec le furathiocarb

Les attaques de thrips (*Thrips tabaci* Lind) et à un moindre degré de la teigne du poireau (*Acroleopsis assectella* Z.) provoquent des pertes élevées en qualité et en récolte dans les cultures de poireaux (*Allium porrum* L.). Toutefois, les thrips sont paarticulièrement difficiles à combattre. Dans la practique les cultures de poireaux sont habituellement intensément traitées par des pulvérisantions pendant la totalité de la saison et le pourcentage de plantes non commercialisable est souvent beaucoup trop élevé, particulièrement dans les cultures d'automme et les cultures précoces d'hiver. Depuis 1996, le furathiocarb est recommandé pour la lutte contre le thrips dans les champs de poireau, seulement deux traitement sont permis. Pendant 1996 et 1997, des experimentations ont été réalisés pour déterminer un seuil d'intervention pour le thrips, basé sur le nombre de larves par plante. L'activité du vol a aussi été suivi dans ces champs de poireaux aves des pièges chromatiques bleus. Le seuil d'intervention est près d'un moyen de dix larves par plante. Une deuxième pulvérisation après trois semaines est nécessaire pour obtenir des cultures tout à fait vendables. L'activité de vol de thrips a été observée de la fin de juillet jusqu'à le 20-25 août. Un pic de vol a lieu le 21 août 1996 et le 27 août 1997.

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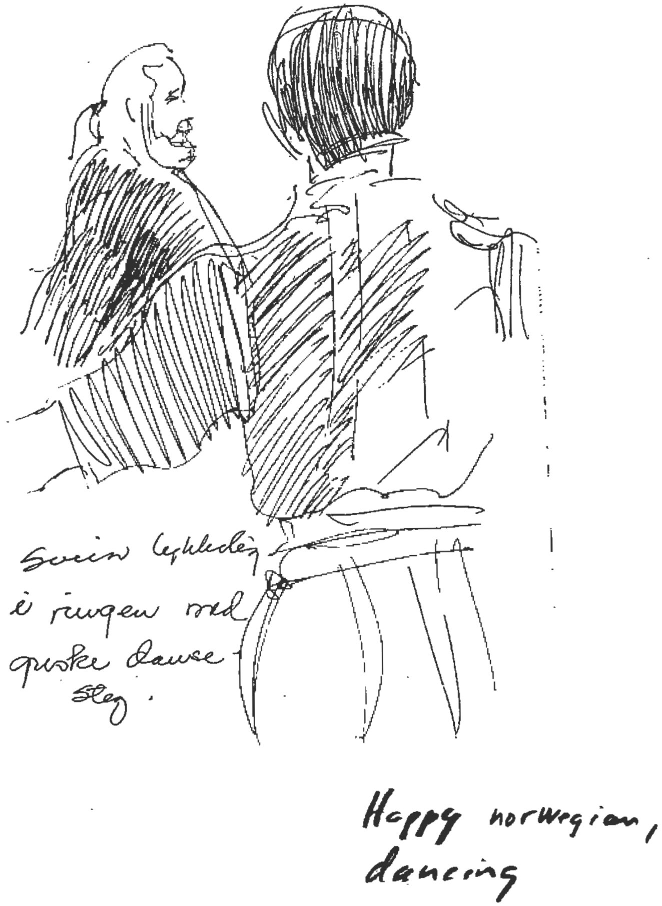

A happy Norwegian, Svein Lilleengen, joining in with the local folk dancers.
(Sketch by Aud Lilleengen –1997)

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