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Integrated Pest Management of Aphids on Outdoor Lettuce Crops

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Contents of report

1. Practical section for growers

The overall objective was to develop an integrated pest management system for aphids on outdoor lettuce based on sound scientific principles. To achieve this the project addressed three major questions:

1. Which are the most important aphid species, when do they colonise lettuce crops and can their arrival be predicted?
2. Can novel methods be devised to prevent colonisation of lettuce crops?
3. If aphids do colonise lettuce, how can they be controlled?

The important aphid species on lettuce

Water traps and plot of lettuce planted sequentially from May to August at HRI Wellesbourne, HRI Kirton and in Lancashire were used to identify the species of aphid colonising lettuce and the periods of the risk of infestation. The four species of aphid found to infest lettuce were the lettuce root aphid, *Pemphigus bursarius,* and three species that colonise the foliage, the currant-lettuce aphid, *Nasonovia ribisnigri,* the peach-potato aphid, M*yzus persicae,* and the potato aphid, *Macrosiphum euphorbiae*. The lettuce root aphid and the currant lettuce aphid are specific to lettuce in summer while the other two species are highly polyphagous, feeding on a wide range of plant species in summer.

The risk of infestation was found to change through the season. Lettuce crops sown very early are unlikely to be colonised by aphids. However, in June and July the risk of infestation by all four aphid species becomes high, although the exact timing of aphid immigration differs between species and is weather-dependent. In mid-late summer, following a natural decline in aphid numbers, there is usually a period when the risk of infestation by any aphid species is low. However, in the autumn, the risk of infestation by the currant-lettuce aphid increases once again.

Preliminary forecasts have been developed to determine the timing and duration of aphid colonisation, although these will require further validation. The changing pattern of risk due to colonisation by the four aphid species means that it should be possible to adopt different control strategies at certain times in the season.

Novel ways of preventing aphids from colonising lettuce

Laboratory experiments showed that once the lettuce root aphid colonises lettuce the newly born young move to the roots within an hour, while the winged currant-lettuce aphid find the heart of the plant within a day. Control strategies therefore need to be targeted very carefully. Further work in this section of the project focussed on the currant-lettuce aphid.

Aphids locate their host plants using a combination of sight and smell. Collaborative research between IACR Rothamsted and HRI Wellesbourne has attempted to exploit this behaviour by preventing currant-lettuce aphids from colonising lettuce. Currant-lettuce aphids spend the winter as eggs on blackcurrant. The eggs hatch in the spring, and after completing one or two generations on currant, winged aphids fly to lettuce. The aim of the research was to use the chemicals from blackcurrant to make the aphids 'think' that they are in a field of blackcurrant, rather than in a crop of lettuce, and therefore prevent them landing on the plants. Detailed experiments in the laboratory have shown that it is possible to modify aphid behaviour in the

presence of volatile chemicals from blackcurrant so that their natural attraction to lettuce is 'switched off'. There are 11 compounds in the volatiles from blackcurrant to which the aphid responds, but a mixture of all these chemicals seems to be required to give the desired response. More work is required before a similar response is achieved outdoors.

How can colonising aphids be controlled?

The third part of the project was concerned with the control of aphids once they have colonised the crop. Apart from insecticides, possible approaches include growing lettuce varieties resistant to aphids or killing aphids with natural enemies (biological control). During the first two years of the project these approaches were investigated separately, before being combined in an IPM strategy.

Lettuce varieties resistant to the lettuce root aphid or to the currant-lettuce aphid have been developed by seed companies. Both types of resistance gave good aphid control.

An isolate of the fungus *Metarhizium anisopliae* was identified which was specific to the lettuce root aphid. Spores of this fungus were incorporated into module compost and achieved effective control of the lettuce root aphid in the field.

The number of insecticides available to growers for control of aphids on lettuce has decreased in recent years. Early on in the project a number of new compounds for aphid control in lettuce were evaluated by ADAS. As a result of these trials, the HDC have obtained Off-Label Approval for imidacloprid seed treatment and are in the process obtaining residue data for a SOLA for triazamate, which is applied as a foliar spray.

IPM strategy

The components of a potential IPM strategy identified above were brought together in the last two years of the project (1996-97) to see how well they would perform in combination. The trials were done in plots of lettuce grown at HRI Wellesbourne, HRI Kirton and on a commercial farm in Lancashire.

Aphid monitoring data collected during 1994 and 1995 had defined clearly the periods of differing risk during the season, when crops were exposed to varying pressure from aphids feeding on the roots or on the foliage. A number of control strategies were targeted at each of these risk periods. In all cases, these were compared with a programme of routine twice-weekly applications of pirimicarb. The relative success of the various strategies was determined at harvest when the lettuce heads were assessed for yield, quality and pest damage.

It was not possible to test all combinations of the control components within the trials. However, the combinations chosen produced several important results. Firstly, lettuce varieties resistant to the lettuce root aphid and currant-lettuce aphid controlled these species effectively. However, insecticides were still required at times when other aphid species were present.

Of the insecticides used, routine twice-weekly sprays of pirimicarb rarely gave effective control of aphids on the foliage, or on the roots. In contrast, sprays of triazamate, which were applied only when aphids were present on the foliage, resulted in effective control and fewer treatments. In addition, treating the lettuce seed with imidacloprid often reduced the numbers of triazamate sprays required subsequently. When applied in response to the presence of foliage aphids, triazamate also gave good control of the lettuce root aphid, and to a certain

extent, masked the effects of either host plant resistance, *Metarhizium anisopliae* or imidacloprid seed treatment against this pest. Further work is required to optimise aphid control using triazamate.

Conclusions

It is essential that lettuce growers have a choice of effective aphicides from different insecticide classes available for aphid control. This project has identified two new insecticides, imidacloprid and triazamate; one of which is already available with Off-Label Approval. However, the threat of insecticide resistance means that growers must remain vigilant and avoid being reliant on one or two chemicals. Again, the project has shown that knowledge of aphid biology, coupled with regular crop monitoring, can facilitate the deployment of a variety of control methods, each being targeted at the most appropriate time. In addition, effective control can often be achieved with fewer applications of insecticides than are sometimes applied currently. Finally, this project has demonstrated that, although not all options are as yet part of current commercial practice, non-insecticidal techniques such as resistant varieties, natural enemies and chemicals which modify aphid behaviour all provide good opportunities for aphid control in the future.

2. Introduction

This project addressed directly a problem specific to lettuce growers, and therefore will have economic benefits strictly relevant to the production of lettuce in the UK. It also impacts on the wider concerns relating to the intensive use of pesticides in the environment and on pesticide residues in food crops. These latter points are related directly to MAFF policy on the future direction of pesticide use in the UK, and as such the project has pulled towards the market some of the strategic research on novel pest control methods which MAFF has funded in recent years.

The overall objective was to develop an integrated pest management system for aphids on outdoor lettuce based on sound scientific principles. The specific objectives of the project were:

1. To develop and validate forecasts that predict the timing and duration of migration of *P. bursarius* and *N. ribisnigri* from their winter host plants to lettuce.

2. To quantify how rapidly aphids reach preferred feeding sites after initial host location to enable different components of the IPM system to be targeted effectively.

3. To identify novel host plant volatiles that affect aphid colonisation of lettuce.

4. To begin to quantify the impact of these semiochemicals in laboratory experiments.

5. To assess the suitability of new selective insecticides, e.g. triazamate, imidacloprid and pymetrozine, and novel biopesticides, such as *M. anisopliae*, for inclusion in an IPM programme. These were compared against current industry standards (pirimicarb and demeton-s-methyl) for persistence, selectivity and efficiency against *P. bursarius* and *N. ribisnigri*.

6. To bring together a range of control strategies in an integrated system targeted specifically at key stages in the pest life cycle, and to compare the effectiveness of an IPM programme with control methods used currently to achieve a marketable crop.

Table of tasks

TASK	Year			
	1	2	3	4
1. Forecast development	HRI	HRI	HRI	HRI
2. Forecast validation	HRI, ADAS	HRI, ADAS	HRI, ADAS	HRI, ADAS
3. Feeding site location	HRI	HRI	HRI	
4. Host plant volatile identification	IACR	IACR	IACR	IACR
5. Quantify impact of semiochemicals in laboratory experiments	HRI, IACR	HRI, IACR	HRI, IACR	HRI, IACR
6. Efficacy of novel products	ADAS	ADAS		
7. Compare IPM v conventional systems of control		HRI	HRI, ADAS	HRI, ADAS

This scheme incorporates modifications made at the end of year 1 due to changed priorities in the work on semiochemicals.

3. Forecast development and validation

The objective of this part of the project was to collect data on phenology of aphid species and then to develop forecasts to predict the timing of key events in the colonisation of crops by aphids. This will enable growers to time control measures accurately. The aphid species studied were the lettuce root aphid, *Pemphigus bursarius,* and three species that colonise the foliage, the currant-lettuce aphid, *Nasonovia ribisnigri,* the peach-potato aphid, M*yzus persicae,* and the potato aphid, *Macrosiphum euphorbiae.* Previous work at Wellesbourne and in other parts of Europe has indicated that these four aphid species are the major pests of lettuce grown outdoors (Reinink and Dieleman, 1993). *Pemphigus bursarius* and *N. ribisnigri* are specific to lettuce in summer while *M. persicae* and *M. euphorbiae* are highly polyphagous, feeding on a wide range of plant species in summer (Tatchell, Parker and Woiwod, 1983).

3.1. Aphid phenology

3.1.1. Materials and Methods

Aphid populations were monitored by two methods, each providing complementary data:

Trapping winged aphids. Water traps, constructed of yellow plastic washing-up bowls (25 x 31 x 12cm deep), painted black on the outside and fitted with vertical baffles (20 cm wide x 30 cm high) made from yellow Correx, were placed on pieces of artificial grass (1 x 1 m) on the perimeter of lettuce fields at HRI Wellesbourne (1994-97), HRI Kirton (1994-97), at two sites in Kent (1994-97), at Burscough, Lancashire (1994-97), at one site in Cambridgeshire (1995-97) and one site on Humberside (1995). At each site two traps were placed in `permanent' locations close to, but not within, the lettuce crops. Most traps were emptied twice a week, or once a week at the more remote sites. The water trap samples were sorted at HRI Wellesbourne and the alates of species known to infest lettuce were identified and counted.

Sampling lettuce plants. During the summers of 1994-97, plots of lettuce (variety `Saladin') were planted at HRI Wellesbourne, HRI Kirton and within commercial crops near Burscough in Lancashire. The lettuce was grown as a commercial crop, except that insecticides were not applied. Five sequential plantings (May to August) were made at HRI Wellesbourne and HRI Kirton, while three to five plantings were made in Lancashire. The planting dates of plots grown in each year are given in Table 1.

All plots were sampled once a week from mid-May until mid-October. Individual plots were sampled for eight to nine weeks depending on the time of year and hence the rate of growth of plants. Two plots at each location were sampled for much of the time, to ensure continuity. Twenty plants (ten plants at Burscough when two plots were sampled) were sampled destructively from each plot on each sampling occasion. The aerial parts of the lettuce plant were placed individually in plastic bags and returned to the laboratory where all aphids were removed carefully and stored in alcohol for later identification at HRI Wellesbourne. *Pemphigus bursarius* infestations on the roots of lettuce were scored using a logarithmic scale (Table 2).

3.1.2. Results and Conclusions

Trapping winged aphids

The numbers of alate (winged) aphids of the four species in water trap samples from two sites in Kent (J.J. Barker and Intercrop), HRI Wellesbourne, HRI Kirton, and at Burscough, Lancashire are presented for the four aphid species in Figures 1-4. Data for 1994-97, the four years of the project, are shown for comparison. Data for the Cambridgeshire and Humberside sites, where sampling was not continuous, are not presented graphically. There were large differences in the numbers of aphids recorded in water traps at the different sites. The scales on the *y*-axis in Figures 1-4 differ between species and sites to facilitate the interpretation of the phenology. The absence of a line for a particular year indicates no alates caught.

Sampling lettuce plants

The numbers of alate (winged) and adult apterous (wingless) aphids sampled from the foliage of twenty plants from sequentially-planted lettuce plots at HRI Wellesbourne, HRI Kirton and Burscough in 1997 are presented by species in Figures 5-7. The percentage of plants where roots were infested by *P. bursarius* in 1997 are presented in Figure 8. Similar data for the years 1994-96 were presented in previous Annual Reports. The numbers of immature aphids were also counted, but not identified to species, and the data are not reported here.

The data for the four years and three sites indicate clearly that the time crops became infested can vary considerably between sites and between years (Table 3).

Myzus persicae

Between 0.5 and 3070 alate *M. persicae* were captured/trap/site/year in the two yellow water traps located at each aphid monitoring site (Fig 1). In general, the largest numbers were captured at HRI Wellesbourne and the smallest at Burscough in Lancashire. In 1995, the year when the largest numbers of aphids were captured, *M. persicae* flights began at most sites before the traps were placed outside in early May. Each year the largest numbers of aphids were captured in water traps during July-August. Aphid numbers then declined, but in some years, smaller numbers of aphids were captured in September-October.

The numbers of aphids recorded in samples taken from plants in the sequentially-planted monitoring plots followed a similar pattern (Fig. 5). Depending on the year, the largest numbers of apterous *M. persicae* were recorded from late June through to August. Aphid numbers then declined rapidly, the mid-season aphid crash usually occurring during late July-early September. In some years, aphid numbers increased again during September-October.

Macrosiphum euphorbiae

Between 3 and 360 *M. euphorbiae* alates were captured/trap/site/year in the two water traps placed at each site (Fig. 2). As with *M. persicae*, the largest numbers of alate aphids were captured at HRI Wellesbourne and the smallest in Lancashire. Similarly, on several occasions, alates were present before the traps were in place in early-mid May.

Each year the largest numbers of alate *M. euphorbiae* were captured in water traps during July-August. Aphid numbers then declined and very few alates were recorded in September-October. Depending on site and year, the first apterae were found on plants between 2 May

and 19 June and the largest numbers occurred between mid-June and mid-August (Fig. 6). The rapid mid-summer decline in numbers occurred between mid-July and mid-September. In some years, the numbers of apterae increased again in September and early October.

Nasonovia ribisnigri

Few alate *N. ribisnigri* were recovered in the water traps (Fig. 3) and these data cannot be used to develop or validate forecasts. However, considerable numbers were found on plants in the monitoring plots, particularly in Lancashire (Fig. 7). Once again there were two periods of infestation. The first apterae were found on plants between early June and mid-July, with the largest numbers during July and early August. Numbers then decreased during mid-July to early September before increasing again during September and October. In many cases, the larger infestations of *N. ribisnigri* on plants were recorded in September-October rather than in mid-summer.

Pemphigus bursarius

During 1994-97, between 0 and 93 aphids/trap were captured at each site during each season, using two water traps/site (Fig. 4). The earliest date by which aphids were captured in water traps was 30 May, at Kirton, in 1997. The latest date was also at Kirton, on 25 July 1996. Alate aphids were also recovered in the samples taken from the foliage of lettuce plants in the monitoring plots.

In 1996 and 1997, the late summer migration of alates back to their overwintering sites on poplar was detected in late September and early October at several sites.

At no time in 1997 were the roots of all plants infested (Fig. 8).

3.2 Aphid forecasts

Development of preliminary forecasts of the times of crop colonisation

The data collected from the water traps and sequentially planted plots of lettuce confirmed that four discrete periods could be identified during which the relative abundance of the four pest aphid species of lettuce was different. These can be described as follows:

1. **Low** risk of attack by both foliage-feeding and root aphids e.g. in spring, in the period prior to the first flight of all four aphid species to colonise lettuce.

2. **High** risk of attack by both foliage-feeding aphids and by *P. bursarius* e.g. in mid-summer following the start of immigration by alate aphids to lettuce.

3. **Low** risk of attack by foliage-feeding aphids, but **high** risk of attack by root aphids. This occurs rarely.

4. **High** risk of attack by foliage-feeding aphids and **low** risk of attack by *P. bursarius*, e.g. when numbers of *N. ribisnigri* increase in the late summer and early autumn but immigration to lettuce by alate *P. bursarius* has ceased.

This scheme indicates that the risk to crops of aphid infestation changes with time during the season (Fig. 9). Control strategies tailored to each of these periods could be deployed within an

IPM programme. The precise timing of these risk periods varies between years. For example, in 1996, the period of high infestation by aphids feeding on the foliage in mid-summer occurred particularly late (Table 3). Forecasts are required, therefore, to target the control strategies for each period of differing risk.

Forecasts were developed to predict, where appropriate, the following events for each species:

- Start of colonisation
- Peak of infestation
- End of immigration
- Mid-season crash
- Start of autumn colonisation

The data available for forecast development are summarised in Table 4. They include information from the water traps and sequentially-planted plots of lettuce used in the present study, data and fitted equations from the Rothamsted Insect Survey (provided by Richard Harrington, IACR Rothamsted) and a preliminary forecast of the start of *P. bursarius* immigration developed by HRI and ADAS (Collier *et al.*, 1994).

The four aphid species were separated into two groups:

- Anholocyclic species – *M. persicae* and *M. euphorbiae* - which in the UK overwinter usually as adults and nymphs. Previous studies by Richard Harrington and colleagues at Rothamsted (Harrington *et al.*, 1990) have shown that there is a strong negative correlation between the mean January-February air temperature and the date on which the first alate aphid of each of these species is captured in suction traps.

- Holocyclic species – *N. ribisnigri* and *P. bursarius* - which overwinter in the egg stage in the UK. It is likely that the start of colonisation is related to spring temperatures.

Aphid biology determined the type of forecast that was developed for each species. For the anholocyclic species (*M. persicae* and *M. euphorbiae*), water trap and plant monitoring records were correlated with relationships determined previously from Rothamsted suction trap data, to derive equations predicting the key events in colonisation. For the two holocyclic species (*N. ribisnigri* and P. *bursarius*), relationships were derived between the key events in colonisation and the numbers of day-degrees accumulated from 1 February each year.

All possible relationships were examined. Table 5 shows the relationships which fitted best for each colonisation event for each species. These relationships are presented graphically in Figures 10 - 13. Other statistically significant relationships included strong positive correlations between 1) the date of 10% capture of *M. persicae* in water traps and the date when peak apterae were found on plants (r^2=0.74, N=10, p=0.01), 2) the time of 50% capture of *M. persicae* in water traps and the date when peak apterae were found on plants (r^2=0.78, N=10, p=0.001) and 3) the date of 10% capture of *M. euphorbiae* in water traps and the date when peak apterae were found on plants (r^2=0.74, N=10, p=0.01).

Comparisons between species

For all three foliage-feeding aphid species, the timing of the mid-season crash was highly correlated with the date when peak numbers of apterae were found on plants. This is not surprising, since if aphid numbers are increasing continuously prior to the crash, then it is the timing of the crash that determines the timing of the preceding peak. More surprisingly, the dates of the mid-season crash were similar for all three species (Table 6; Figure 10 - 12). This implies that forecasts developed to predict the timing of the mid-season crash for one species could be used to predict the crash in others. The dates when peak numbers of apterae of each species were found on plants were less highly correlated with one another and there was no correlation between the dates when the first apterae were found.

Limitations of the data

The number of sites (3) and the duration of the project (4 years) determined the maximum amount of information that could be obtained on the development of aphid infestations on lettuce in the untreated monitoring plots. In most cases this was reduced further, either because infestations of one or more of the species were very low or because it was difficult to estimate a particular key event in aphid colonisation from samples collected once or twice per week. Potentially more information was available from the water trap samples because they were also operated at commercial sites. However, once again this information was restricted for certain species because insufficient numbers of aphids were captured in the traps. In addition, it is important to remember that most of the samples were taken only once each week so that this limits the accuracy with which key colonisation events can be estimated.

With the exception of *P. bursarius,* no previous data were available on the phenology of aphids in lettuce crops. Thus the information obtained in the project was used to develop preliminary forecasts which will require further refinement and validation. It was, however, possible to validate the *P. bursarius* forecast developed from data collected prior to this project. However, once again, the low numbers of aphids recovered at certain sites during 1994-97 restricted the amount of accurate information that could be obtained. For example, validations of either 10% or 90% capture of alate *P. bursarius* in water traps may not be particularly useful when based on the capture of very low numbers of insects. As would be expected, forecasts of 50% capture appeared to be the most robust (Table 4).

4. Aphid feeding site location

One of the project's specific objectives was to quantify how rapidly aphids reach preferred feeding sites after initial host location to enable different components of the IPM system to be targeted effectively.

4.1 Materials and Methods

Pemphigus bursarius.

In *P.bursarius* the fundatrigeniae are the winged aphids that migrate from galls on poplar to lettuce. These winged aphids contain many fully developed embryos which are produced as soon as the alatae arrive on lettuce.

The behaviour of the fundatrigeniae on lettuce plants was studied in the laboratory. Poplar twigs infested with *P. bursarius* galls were collected during the summer of 1995 and brought into the laboratory. The twigs were placed in a beaker of water and fundatrigeniae which had emerged from the galls were collected. The fundatrigeniae were transferred to another cage where colonisation of young lettuce plants was observed. In a few cases fundatrigeniae were allowed to fly within the cage prior to colonising the lettuce. In other cases the fundatrigeniae were placed directly on a leaf using a brush. A range of behaviours and events were recorded in the process of colonisation and larviposition.

Nasonovia ribisnigri

Winged *N. ribisnigri* were collected from the laboratory culture and starved overnight. One hundred and fifty were released into a large chamber containing a turntable on which 15 lettuce plants of each of two ages (52 and 66 days after sowing) were arranged. Five plants of each of the two ages were removed from the chamber after 24, 48 and 72 hours. Each plant was examined and the number and position of every aphid recorded.

4.2 Results and Discussion

Pemphigus bursarius

* Average time fundatrigeniae remained on leaf was 49 min.

* Fundatrigeniae produced the first nymphs young 9 min. after landing or being placed on the leaf.

* Fundatrigeniae produced young over a period of 34 min.

* A fundatrigenia produced an average of 10 young before leaving the plant.

* The young were born in a sticky pellicle and it took 7 min. for them to free themselves of this material.

* It took the young 11 min. to lie flat on a leaf and a total of 18 minutes before they were mobile.

* The young took an average of 56 min. from birth until they crawled to the edge of a leaf and dropped off into the soil.

The fundatrigeniae that emerge from a newly-opened gall are larger than those which emerge after the gall has been open for two or three weeks. Thus the early migrants have the highest breeding potential. Earlier studies at HRI Wellesbourne showed that a large fundatrigenia could produce, on average, 16 young in 75 min (Dunn, 1959).

Nasonovia ribisnigri

Of the 150 aphids released in the experiment 73% were found on plants. Of these, 39% were on older plants and 61% on younger plants. Twenty three percent of aphids were recorded towards the distal (outer) part of leaves, 50% on the proximal parts (close to the stem of the plant) and 27% were recorded on the cluster of young developing leaves around the growing point. Approximately 18% of aphids were collected after 24h, 33% after 48h and 49% after 72h. Very few nymphs were produced during the course of the experiment.

These experiments indicate that both species become inaccessible for control by insecticide sprays very rapidly after colonisation. Nymphs of *P. bursarius* leave the lettuce foliage within an hour. Winged *N. rabisnigri* colonised the heart of the plants as soon as they were observed.

5. Host plant volatile identification

In this part of the project the aim was to identify semio-chemicals in lettuce and blackcurrant which might influence the behaviour of *N. ribisnigri*. Electrophysiological studies were done to determine which chemicals the aphids responded to.

5.1 Materials and Methods

Three extraction techniques were used to isolate volatiles from host plant material. The particular technique was determined by the nature of the plant material and the requirements for the associated chemical identification.

Vacuum distillation. Lettuce volatiles were obtained by vacuum distillation of fresh plant material. 1-2 kg of lettuce leaves were placed in a vacuum dessicator and distilled under reduced pressure for 24 hours. Volatiles, including water, were collected in two traps in series, the first of which was cooled in an ice/salt mixture and the second with dry ice/acetone. The water and volatile organic material in the cold traps was extracted with ether, which was then dried over $MgSO_4$, concentrated under a stream of nitrogen and stored at -20°C in microvials.

Air entrainment. Volatiles were collected from cut shoots of blackcurrant using a dynamic headspace (air entrainment) technique (Blight, 1990). Cut stems, of the blackcurrant variety 'Ben Sarek', were contained in water in conical flasks placed in a glass culture vessel. Volatiles were drawn from the vessel, using purified air, onto a tube of the adsorbant Porapak Q. At the conclusion of the entrainment, volatiles were eluted from the Porapak with re-distilled ether, concentrated under a stream of nitrogen and stored at -20°C in microvials.

Nitrogen-assisted microwave extraction. Volatiles from excised blackcurrant leaves were obtained by the nitrogen-assisted microwave extraction technique (Craviero *et al.*, 1989). 20 g of fresh leaf material were placed in a flask in a modified microwave oven and the microwave switched on for 15 sec (high level). Volatiles distilling from the plant material were swept from the flask with a stream of nitrogen (150 ml/min) and trapped in 50 ml re-distilled hexane. The sample was dried with $MgSO_4$, concentrated under a stream of nitrogen and stored at -20°C in microvials.

Gas chromatography (GC). Samples of volatiles were analysed on a 50 m x 0.32 mm (internal diameter) methyl silicone bonded-phase (HP-1) fused silica capillary column fitted in a Hewlett Packard 5890 gas chromatograph, equipped with a cold on-column injector and a flame ionisation detector (FID). The carrier gas was hydrogen and the oven temperature was maintained at 40°C for 2 min and then programmed at 10°/min to 250°C.

Coupled GC-Mass Spectrometry (GC-MS). A capillary column (50 m x 0.32 mm id HP-1) fitted in a Hewlett Packard 5890 gas chromatograph was coupled directly to the MS (VG Autospec double-focussing). Ionisation was by electron impact at 70eV with a source temperature of 200°C. The GC column was maintained at 30°C for 5 min and then programmed at 5°/min to 250°C. The carrier gas was helium.

Electrophysiology. EAG. Recordings from the whole antenna were made using Ag-AgCl glass electrodes. The signals generated by the antenna were amplified, stored on disc and analysed with a custom-made software package (Syntech).

Single Cell Recording - SCR. Recordings from individual olfactory cells were made with tungsten microelectrodes. The indifferent electrode was positioned in the first antennal segment and the recording electrode was then brought into contact with the rhinarium until impulses were recorded.

Coupled GC-electrophysiology (GC-EAG and GC-SCR). For both systems, the effluent from the GC column was split equally between the FID of the GC and the electrophysiological preparation, enabling simultaneous monitoring of the GC column effluent.

5.2. Results and Conclusions

Lettuce volatiles: Although GC analysis of the lettuce vacuum distillate showed the sample to contain only trace amounts of volatile material, coupled GC-SCR studies located four components with high electrophysiological activity, three of which are shown in Figure 14. The very small quantities of chemical to which the aphids respond have meant that it has not been possible to identify these compounds during the project.

Blackcurrant volatiles: GC analysis showed that the air entrainment and nitrogen assisted microwave extracts of blackcurrant were essentially similar, with only minor differences in composition. However, since the microwave sample contained significantly more material, this sample was used for coupled GC-EAG studies and eleven electrophysiologically active components were located (Figs. 15 and 16). This is the first time that the coupled GC-EAG technique has been used with aphids.

Tentative identifications of these compounds were obtained by GC-MS and their identities confirmed by coinjection with authentic compounds on both polar and non-polar GC columns (Table 7).

6. Quantify impact of semiochemicals in laboratory experiments.

Having identified a number of compounds in lettuce and blackcurrant to which alate *N. ribisnigri* respond electrophysiologically (section 5), it was necessary to determine how these compounds affected the behaviour of the aphids.

6.1 Methods

6.1.1 Laboratory studies

Experiments were done in a Petterson olfactometer to test the behavioural response of winged *N. ribisnigri* to host plant volatiles. A weak air stream was drawn towards the centre of the olfactometer from each of the four side arms. The test stimulus was placed at the end of one side arm, while the other three served as controls. A winged *N. ribisnigri* was introduced into the centre of the olfactometer and its activity recorded over a period of twelve minutes. The observations made were the time spent in the treated arm, the number of times it entered the treated arm and the arm first entered by the aphid. Each volatile being compared was tested on a single day with a fresh aphid for each compound. This was considered a replicate and there were twelve replicates for each experiment. The untreated control was with no chemical in any arm. The results were analysed by paired t-test; the mean time spent, the mean number of entries or the first entry were compared with the mean value for the control arm.

A series of experiments were done. In all cases 20 µl extracts or pure compounds were applied to filter paper and placed in the treatment arm of the olfactometer. Individual experiments were done to determine:

A The response to whole extracts from the blackcurrant varieties 'Ben Sarek' and 'Baldwin' either in the presence or absence of lettuce leaves. Treatments were:
- 'Ben Sarek' extract
- 'Baldwin' extract
- Lettuce leaf + 'Ben Sarek' extract at 25 g/ml.
- Lettuce leaf + 'Ben Sarek' extract at 25 g/ml.

B The response to lettuce leaf on its own, the response to lettuce leaf with whole blackcurrant extract (Ben Sarek) and lettuce leaf with blackcurrant leaf. Also to compare these with the response to extract on its own and blackcurrant on its own. Treatments were:
- Lettuce leaf
- Lettuce leaf + 'Ben Sarek' extract at 25 g/ml.
- Lettuce leaf + 'Ben Sarek' leaf
- 'Ben Sarek' extract at 25 g/ml.
- 'Ben Sarek' leaf

C Determine the dose response relationships of blackcurrant extract (Ben Sarek) on its own. Treatments were:
- 'Ben Sarek' extract at 250, 25, 2.5, 0.25 or 0.025 g/ml.

D Determine the dose response relationship to blackcurrant extract (Ben Sarek) in the presence of lettuce leaf. Treatments were:

- Lettuce leaf
- Lettuce leaf + 'Ben Sarek' extract at 25, 20, 15, 10, 5 or 2.5 g/ml.

E Determine the response to individual components of volatiles from blackcurrant. Treatments were:
- Lettuce leaf
- 'Ben Sarek' extract at 25 g/ml.
- Each of the individual components of the volatiles from blackcurrant (see Table 7)

F Determine the response to lettuce in the presence of individual components of volatiles from blackcurrant. Treatments were:
- As for experiment E except that a lettuce leaf was included in the arm of the olfactometer with each individual components of the volatiles from blackcurrant (see Table 7)

G Determine the response to a synthetic mixture of the individual components of volatiles from blackcurrant alone or in the presence of lettuce. Treatments were:
- Lettuce leaf
- 'Ben Sarek' extract at 25 g/ml.
- Synthetic mixture at 1, 0.1 or 0.01 mg/ml (mixture contained all compounds in Table 7 in equal proportions)
- Lettuce leaf + synthetic mixture at 1, 0.1 or 0.01 mg/ml (mixture contained all compounds in Table 7 in equal proportions)

6.1.2. Field cage and glasshouse studies

A small field cage experiment was done to quantify the effect of the extract from 'Ben Sarek' on the colonisation of lettuce plants by *N. ribisnigri*. The experiment was repeated three times. For each replicate two blocks of three cages were arranged at right angles to each other. Each block had one control cage and two treated cages. Four trays, each with ten young lettuce plants, were placed at each end of each cage. Amongst the lettuce at one end of the treated cages was placed a vial containing a wax formulation 50 g/ml of Ben Sarek extract. Alate *N. ribisnigri* were released in the centre of the cage; 100 were released in replicate 1 and 2 while 200 were released in replicate 3. The number of aphids on the plants were recorded at 2, 5.5, 9, 24 and 48 h after release.

As the field cage experiments were found to be affected by wind, a further experiment was done in an array of three small greenhouses. The design was as for the field cages except 400 aphids were released and plants were sampled 2, 5.5, 7, 9, 24 and 48 h after release.

6.2 Results and Conclusions

6.2.1 Laboratory studies

Experiment A indicated that the total time spent and the number of entries into the treatment arm of the olfactometer by alate *N. ribisnigri* were significantly less than the untreated control for the extract from the blackcurrant variety 'Ben Sarek' but not for the variety 'Baldwin' (Fig. 17). This suggests a repellence. Ben Sarek was therefore used for all further experiments.

There was a significant attraction of alate *N. ribisnigri* to lettuce, but this could be masked in the presence of Ben Sarek extract (experiment B) (Fig. 18). The approximate concentration of Ben Sarek extract required to elicit a significant behavioural response in alate *N. ribisnigri*

(experiment C) was 2.5 g/ml, but the response was not significantly greater at higher concentrations (Fig. 19). When concentrations of this order were used in the presence of lettuce (experiment D), it was found that the significant attraction to lettuce was masked at all concentrations of extract tested, and significant repulsion occurred at a number of concentrations from 5 to 25 g/ml of extract (Fig. 20).

Initial studies identified 11 compounds within the volatiles from blackcurrant to which alate *N. ribisnigri* showed an electrophysiological response (see section 4). When the response of alate *N. ribisnigri* to each of these 11 compounds was tested (experiment E) no individual compound showed a significant repellence to the aphids. Interestingly, alate *N. ribisnigri* showed a significant attraction to (E)-2-hexenal, α-terpinolene and chrysanthenone on their own as measured by either the time spent in the treatment arm, the number of entries to that arm or the first arm entered (Fig. 21). These results suggest that there may be opportunities to use these compounds within a trap for monitoring the colonisation of lettuce by alate *N. ribisnigri*. When aphids were presented with each of the 11 compounds in the presence of lettuce (experiment F), none of the compounds resulted in significant repulsion though with many the attraction to lettuce was switched off (Fig. 22).

A synthetic mixture of blackcurrant volatiles made up of each of the 11 compounds in equal proportions (experiment G) did repel alate *N. ribisnigri* at a concentration of 1 mg/ml and at this concentration the attraction to lettuce was turned off (Fig 23).

These laboratory experiments indicate that the chemical ecology of *N. ribisnigri* is very complex. Alates of this species have a very strong attraction to the volatiles from lettuce. Similarly, these aphids are repelled by the volatiles from blackcurrant. None of the eleven individual compounds within the whole blackcurrant extract elicit the same behavioural response, but a synthetic mixture of the 11 compounds in equal proportions did repel the aphids.

6.2.2. Field cage and glasshouse experiments

Short-term field experiments examining the impact of volatile chemicals on aphid behaviour are likely to be influenced by wind; aphids will tend to accumulate at the down wind end of the cage. However, over time variability might nullify the effect of wind direction. Unfortunately, all three replicates of the field experiment were affected by a stiff south westerly breeze which resulted in accumulations of aphids at the down-wind end of the cages irrespective of treatment. The results are therefore not presented. There was, however, a reasonable recovery of aphids in the second and third replicates of the experiment which suggests that the methodology may be appropriate during periods of lighter wind.

In the glasshouse there was a similar positional effect with most aphids accumulating on plants at the western end of the glasshouse irrespective of treatment. Again the results are not presented.

7. Efficiency of novel products

7.1 Insecticides

The purpose of this section of the project was to evaluate new and existing insecticides for their efficacy against foliar and root aphids. The single product approved for *P. bursarius* control in the soil is subject to accelerated bio-degradation. Growers therefore relied heavily on sprays of pirimicarb to control this aphid as well as using it to control aphids on the foliage. If growers rely too heavily on this insecticide, insecticide-resistant biotypes may develop, as has already been reported for pirimicarb against *N. ribisnigri* in southern France (Martin *et al.*, 1996). Consequently, there is an urgent need to confirm the performance of new products and collect data on their efficacy in the field.

7.1.1. Materials and Methods

Field experiments were done on commercial farms in Lancashire (Hooton's Farm, Scarisbrick) and Cambridgeshire (Hainey Farm, Barway) in late August and early September 1994, and in late June and early July 1995. The products tested were imidacloprid seed treatment at 2 mg per pelleted seed, pymetrozine applied at 0.8 kg per ha and triazamate at 0.4 l per ha with 0.5 l swirl adjuvant. These were compared with pirimicarb as pirimor at 250 g per ha of product (500 g per l, 500 l per ha) and demeton-S-methyl at 420 ml per ha (580 g per l) and an untreated control.

The seed treatment was done at HRI Wellesbourne in 1994 and by Seedcote Systems Ltd in 1995.

Both experiments were a fully randomised block design replicated five times. Foliar spray treatments were applied onceapproximately 14 days after planting. Assessments of aphid numbers were made pre-treatment, 2 days after treatment (DAT) and again between 9 and 12 DAT.

7.1.2. Results and Conclusions

1994

The three novel insecticides, imidicloprid, triazamate and pymetrozine reduced aphid numbers on the foliage significantly, particularly 10 – 12 DAT. They performed as well as or better than the commercial standards demeton-S-methyl and pirimicarb (Table 8 and 9).

These experiments were done after the period of *P. bursarius* infestation and there the control of this species was not tested. Aphid numbers were very low at the Cambridge site and results must be interpreted with caution.

1995

In Lancashire significant differences between treatments were found on both assessment dates. The level of control given by pirimicarb, demeton-S-methyl and pymetrozine was poor, particularly 10 DAT. In contrast, >80% control was achieved with imidacloprid and triazamate (Table 10).
Ambiguous results were obtained from the Cambridgeshire site (Table 11). The experiment was probably influenced by a heavy influx of migrant aphids. It was also possible that the

experimental area was oversprayed by the host farmer (the experiment was located in a commercial lettuce crop), but it was not possible to confirm this.

The two years of insecticide trials have shown conclusively that seed treatment using imidacloprid gives exceptional control of foliar aphids, even where pest pressure is high. In addition, triazamate applied as a foliar spray treatment, can also give better aphid control than existing standards. These two compounds were, therefore, considered for inclusion in an IPM programme.

7.2. Biological control of the lettuce root aphid with the insect pathogenic fungus *Metarhizium anisopliae*

Insect pathogenic fungi are natural regulators of many insects, including aphids, and can cause damaging epizootics. They may be suitable for the biological control of *P. bursarius*. Natural infections by fungi of *Pemphigus bursarius, Pemphigus betae* (the sugar beet aphid) and *P. trehernei* (the salt marsh aphid) have been observed, but their potential for biocontrol has not been studied.

In previous work, an isolate of the fungus *Metarhizium anisopliae* was identified with virulence to *P. bursarius*. This fungus was isolated originally from *P. trehernei*. In laboratory bioassays, approximately 90% of *P. bursarius* sprayed with a suspension of infective spores of *M. anisopliae*, at a concentration of 1×10^7 ml^{-1}, died within ten days of inoculation. The estimated median lethal dose at ten days post inoculation was 57 conidia per insect (fiducial limits = 45 – 71). The fungus had no significant effect on the mean number of offspring produced per aphid, but it sporulated profusely on cadavers, producing approximately 4×10^6 conidia per cadaver 14 days after treatment.

The fungus was also infective to aphids in preliminary field experiments done in 1994, in which conidia were incorporated into compost modules in which plants were raised before planting in the field. Evidence from this field experiment and laboratory bioassays indicated that the fungus could spread effectively from the module through colonies of *P. bursarius* feeding on roots of lettuce plants. Insect pathogenic fungi do not grow saprophytically along plant tissues; the most likely method of spread of the fungus outside the module is by contact between infected and non-infected aphids. Hence, an efficient strategy for using the fungus for biocontrol would be to incorporate a high dose of inoculum into a small module, maximising the probability of infecting the first colonisers after planting and initiating an epizootic.

7.2.1. Materials and Methods

The ability of *M. anisopliae* to control populations of *P. bursarius* in the field was measured in 1994 and1995. Conidia were produced in bulk by growing the fungus on autoclaved bulgar wheat, yielding 5×10^9 to 1×10^{10} spores g^{-1}. The conidia were harvested in 0.05% Triton X-100 wetting agent and incorporated at a rate of 10^8 ml^{-1} into compost modules (25 ml volume) in which lettuce seedlings ('Saladin') were raised and then transplanted into the field using a commercial bed system. The experiments were timed to coincide with the major period of infestation by *P. bursarius*. Treated and untreated plants (two replicates) were sampled on 18 occasions over ten weeks (n = 4) and the number of lettuce root aphids on each plant was counted.

7.2.2 Results and Discussion

The results for both 1994 and 1995 followed a similar pattern. Those for 1995 are presented. High levels of infection were observed on plants treated with the fungus (Figure 24) and the fungus infected aphids feeding o9n roots outside the module. The first infection of root aphids by *M. anisopliae* was observed \approximately three weeks after planting. Forth both replicates, the peak population on treated plants (seven weeks after planting was reduced by approximately 80%). Note that the plants were not placed under water stress in this study. As a result of these promising experiments *M. anisopliae* was included in an experimental IPM programme for the control of *P. bursarius*.

8. Comparison of IPM and conventional control systems

The aim of this series of experiments was to take components of a potential IPM programme which had been investigated separately in the first two years of the project, and integrate them into programmes designed to test how well they would perform in combination under commercial field conditions.

A key finding from the aphid monitoring (phenology) work was that it was clear that there were different risk periods during the season when crops would be exposed to high or low pressure from root and foliar aphids. This feature of aphid infestation on lettuce was exploited to produce a 'matrix' approach (Table 12) to the selection of appropriate control measures for inclusion in an IPM programme on lettuce plantings made at different times during the seasons.

1996 work

The principal aim of the 1996 work was to test the hypothesis that different combinations of control strategies could be employed at different times of the season. Three experiments designed to test this hypothesis, using a range of the options given in Table 12, were developed. In summary, these were:

- Experiment 1 - a high input programme in early summer required when the risk of foliar and root aphid infestation was high; two experiments were done, one at HRI Wellesbourne at one in a commercial lettuce crop (courtesy of WCF Ltd) in Lancashire.

- Experiment 2 - a low input programme in late summer when foliar and root aphid pressure was low; two experiments were done, one at HRI Wellesbourne and one at HRI Kirton.

- Experiment 3 - an intermediate input programme in the autumn when foliar aphid (principally *N. ribisnigri*) infestation was high but root aphid risk was low; three experiments were done, one each at HRI Wellesbourne, a commercial site in Lancashire and HRI Kirton.

In addition, a 'managed' approach to deciding on the need for foliar aphid treatments was adopted, using a simple field sampling technique designed to trigger sprays only when aphids were found. This was compared with a 'routine' approach (approximating to current commercial practice) where sprays were applied on a calendar basis.

Full details of the treatments used in the three experiments and the results are given in Table 13.

The key findings were:

- Routine applications of pirimicarb were rarely effective in controlling foliar aphids.
- Effective control of foliar aphids could be achieved with a managed approach to the frequency of application of triazamate, but significant savings in foliar sprays were only possible in those experiments with low aphid numbers.
- The low root aphid populations encountered were generally well-controlled by the control measures employed.
- The principal of selecting control measures according to perceived risk of foliar and root aphid infestation was generally effective.

1997 work

The principal aims of the 1997 work were to:

1. Test further the principal of treatment selection according to risk.
2. To investigate whether the maximum frequency of application of triazamate could be reduced from twice a week to once a week.
3. To test whether using wingless aphids only as a trigger for managed spray treatments was as effective as using the presence of any aphids (winged or wingless).
4. To assess the effectiveness of *M. anisopliae* for root aphid control with and without imidacloprid seed treatment.

Two experiments were designed to test this hypothesis, using a range of the options given in Table 12, were developed. In summary, these were:

- Experiment 1 - a high input programme in early summer required when the risk of foliar and root aphid infestation was high; managed treatments included triazamate applied up to once a week, or up to twice a week. Imidacloprid seed treatments with and without *M.anisoplii* were also included. Three experiments were done, one each at HRI Wellesbourne, HRI Kirton and in a commercial lettuce crop (courtesy of WCF Ltd) in Lancashire.

- Experiment 2 - an intermediate input programme in late summer when foliar aphid pressure was high and root aphid pressure was low. This experiments tested the use of wingless aphids versus all aphids as triggers for managed treatments. Three experiments were done, one each at HRI Wellesbourne, HRI Kirton and in a commercial lettuce crop in Lancashire.

Full details of the treatments used in the two experiments and the results are given in Table 14. The key findings were:

- Routine applications of pirimicarb were again rarely effective in controlling foliar aphids.
- Effective control of foliar aphids could be achieved with a reduced frequency of application of triazamate; within the context of the experiments, using wingless aphids only was an effective trigger for treatment.
- The low root aphid populations encountered were generally well-controlled by *M. anisoplii* alone or by a combination of *M. anisoplii* plus imidacloprid seed treatment. However, these plots also received 2 – 4 sprays of triazamate, shown, in 1996, to be effective for lettuce root aphid control.

In all experiments (1996 and 1997) produce quality was maintained or enhanced by IPM programmes rather than those representing current commercial practice.

9. Technology transfer

This research project has resulted in considerable interaction with lettuce growers, many being involved in project review and planning meetings.

There have been a significant number of presentations on grower and scientific platforms and in the grower and scientific press (Table 15). A number of research publications are yet to be published.

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TABLE 1. Planting dates of sequentially-planted plots of lettuce cv. "Saladin" at HRI Wellesbourne, HRI Kirton and in Lancashire 1994 – 1997 on which aphid populations were monitored.

	HRI Wellesbourne	HRI Kirton	Lancashire
1994	11 May	12 May	9 & 10 May
	16 June	10 June	-
	7 July	30 June	28 June
	26 July	15 July	-
	16 August	10 August	10 August
1995	1 May	1 May	3 May
	1 June	2 June	31 May
	26 June	26 June	26 June
	25 July	24 July	25 July
	29 August	28 August	-
1996	23 April	22 April	15 April
	28 May	20 May	20 May
	19 June	17 June	17 June
	22 July	22 July	19 July
	3 September	27 August	8 August
1997	15 April	24 April	24 April
	20 May	20 May	22 May
	17 June	20 June	23 June
	22 July	22 July	22 July
	26 August	4 September	-

TABLE 2 Logarithmic scoring system used to quantify infestations of Pemphigus bursarius on lettuce roots (after Wright and Wheatley, 1953).

Number *P. bursarius* per plant	Infestation score
0	0
1-4	1
5-11	2
12-33	3
34-100	4
101-300	5
301-900	6
901-2700	7

TABLE 3. Dates by which 100% untreated lettuce plants were infested with foliage-feeding aphids.

	HRI Wellesbourne	HRI Kirton	Burscough
1994	17 May	14 June	18 May
1995	26 May	2 Jun	31 May
1996	5 Jul	10 Jul	24 Jul
1997	16 May	13 Jun	3 Jun

TABLE 4 Data available for development of forecasts for the four pest aphid species of lettuce. MP = *Myzus persicae*, ME = *Macrosiphum euphorbiae*, NR = *Nasonovia ribisnigri*, PB = *Pemphigus bursarius*.

Source	Data available	Event	Species
From this project			
Water traps	First capture	Start of colonisation	MP, ME, PB
	10% capture	Start of colonisation	MP, ME, PB
	50% capture	Peak infestation	MP, ME, PB
	90% capture	End of immigration	PB
	Last capture	End of immigration	PB
	Mid-season crash	Mid-season crash	MP, ME
Sequentially-planted plots	First alate	Start of colonisation	MP, ME, NR, PB
	First aptera	Start of colonisation	MP, ME, NR
	Peak apterae	Peak infestation	MP, ME, NR
	Mid-season crash	Mid-season crash	MP, ME, NR
	First aptera	Start of autumn colonisation	NR
Other sources			
Rothamsted Insect Survey	Data on first capture	Start of colonisation	MP, ME
	Relationships with temperature	Start of colonisation	MP, ME
	Monitoring data	Start of colonisation etc	NR
HRI/ADAS	Preliminary forecast	Start of colonisation	PB

TABLE 5 Equations predicting colonisation events for the four aphid species infesting lettuce. RIS (Rothamsted Insect Survey) relationships are the equations relating the date of first capture of aphids in suction traps to the mean air temperature for January-February for the suction trap nearest to the lettuce aphid monitoring site. Suction traps at Wye, Hereford, Kirton and Preston were used for the Kent, Wellesbourne, Kirton and Lancashire monitoring sites respectively.

Event	Relationship	Statistics
Myzus persicae		
Start of colonisation	10% capture in water traps vs RIS relationship	r^2=0.63, N=18, p=0.001
Peak infestation	50% capture in water traps vs RIS relationship	r^2=0.55, N=19, p=0.001
	Date of peak apterae on plants vs RIS relationship	r^2=0.45, N=11, p=0.05
Mid-season crash	Date of peak apterae on plants vs date of crash	r^2=0.95, N=8, p=0.001
Macrosiphum euphorbiae		
Start of colonisation	Date of first apterae on plants vs RIS relationship	r^2=0.38, N=11, p=0.05
Peak infestation	Date of peak apterae on plants vs RIS relationship	r^2=0.68, N=7, p=0.05
Mid-season crash	Date of peak apterae on plants vs date of crash	r^2=0.68, N=8, p=0.02
Nasonovia ribisnigri		
Start of colonisation	Day-degrees to first apterae on plants (1128 $D^{\circ} > 0^{\circ}C$)	Within $\pm$ 7 days on 8/12 occasions
Peak infestation	Day-degrees to peak apterae on plants (1702 $D^{\circ} > 0^{\circ}C$)	Within $\pm$ 7 days on 6/10 occasions
Mid-season crash	Date of peak apterae on plants vs date of crash	r^2=0.68, N=8, p=0.02
Start of autumn colonisation	Days from first aptera (first colonisation) to first aptera (second colonisation)	r^2=0.54, N=9, p=0.05
Pemphigus bursarius		
Start of colonisation	Day-degrees to 10% capture in water traps (739 $D^{\circ} > 4.4^{\circ}C$)	Within $\pm$ 7 days on 11/18 occasions
Peak infestation	Day-degrees to 50% capture in water traps (813 $D^{\circ} > 4.4^{\circ}C$)	Within $\pm$ 7 days on 14/18 occasions
End of immigration	Day-degrees to 90% capture in water traps (935 $D^{\circ} > 4.4^{\circ}C$)	Within $\pm$ 7 days on 9/18 occasions

TABLE 6 Estimated dates by which the mid-season crash occurred in *Myzus persicae*, *Macrosiphum euphorbiae* and *Nasonovia ribisnigri* on untreated plots of lettuce at HRI Wellesbourne, HRI Kirton and on a commercial farm in Lancashire. Missing records indicate that the date of the mid-season crash could not be estimated accurately.

		M. persicae	*M. euphorbiae*	*N. ribisnigri*
HRI Wellesbourne	1994	26 Jul	18 Jul	18 Jul
	1995	28 Jul	28 Jul	4 Aug
	1996	22 Aug	23 Aug	-
	1997	18 Jul	25 Jul	25 Jul
HRI Kirton	1994	1 Aug	4 Aug	11 Aug
	1995	21 Jul	17 Aug	-
	1996	10 Sep	11 Sep	11 Sep
	1997	-	31 Jul	31 Jul
Lancashire	1994	-	10 Aug	-
	1995	5 Jul	19 Jul	-
	1996	-	14 Aug	21 Aug
	1997	-	-	11 Aug

TABLE 7. Electrophysiologically active compounds identified in blackcurrant volatiles.

(E)-2-Hexenal

5-Methyl furfural

Compound 'X'

1-Octen-3-ol

Sabinene

β-Pinene

α-Terpinolene

Chrysanthenone

Methyl Salicylate

B-Caryophyllene

(E)-β-Farnesene

TABLE 8. The mean number of aphids per plant on plots of lettuce treated with difference insecticides in Lancashire 1994. (Data brack-transformed from $\log_e$ (N+1) transformation).

Insecticide treatment	Time of aphid sample		
	Pre-treatment	2 days after treatment	10 days after treatment
untreated	2.05	2.11	10.70
pirimicarb	2.56	1.28	7.93
demeton-S-Methyl	3.32	1.27	2.67
pymetrozine	2.69	1.77	3.63
triazimate	2.03	1.59	3.32
imidacloprid	1.06	1.06	1.04
F ratio (25 df)	5.08**	3.53*	8.43***
s.e.d.	0.247	0.216	0.456

TABLE 9. The mean number of aphids per plant on plots of lettuce treated with different insecticides in Cambridgeshire 1994.

Insecticide treatment	Time of aphid sample		
	Pre-treatment	2 days after treatment	12 days after treatment
untreated	0.0	0.2	9.8
pirimicarb	0.2	0.0	1.4
demeton-S-methyl	0.8	0.0	5.2
pymetrozine	0.4	0.0	5.6
triazimate	1.6	0.0	1.4
imidacloprid	0.0	0.2	0.0

TABLE 10 The mean number of aphids per plant on plots of lettuce treated with different insecticides in Lancashire 1995.

Insecticide treatment	Time of aphid sample		
	Pre-treatment	2 days after treatment	10 days after treatment
Untreated	10.8	16.3	95.7
Pirimicarb	12.7	8.5	91.5
DSM	16.1	14.2	74.5
Pymetrozine	17.2	12.3	100.9
Triazamate	14.8	2.7	14.5
Imidacloprid	0.9	1.2	4.6
F ratio	4.2**	3.67*	5.58**
SED	4.06	4.83	25.78

TABLE 11. The mean number of aphids per plant on plots of lettuce treated with different insecticides in Cambridgeshire 1995. Mean values are back-transformed from a $\log_{10}$ transformation. F ratios and SEDs quoted are for transformed data.

Insecticide treatment	Time of aphid sample		
	Pre-treatment	2 days after treatment	9 days after treatment
Untreated	3.4	29.0	26.9
Pirimicarb	3.5	33.7	26.9
DSM	3.2	20.8	23.7
Pymetrozine	3.0	45.7	39.4
Triazamate	4.4	20.2	25.2
Imidacloprid	1.0	35.2	19.8
F ratio	(2.25)	(3.91**)	(2.22)
SED	(0.20)	(0.09)	(0.09)

TABLE 12. Matrix of possible control options related to perceived aphid risk on specific plantings of lettuce.

	Foliar aphid	Root aphid	Foliar aphid	Root aphid	Foliar aphid	Root aphid	Foliar aphid	Root aphid
Control Option	**High Risk**	**High Risk**	**High Risk**	**Low Risk**	**Low Risk**	**High Risk**	**Low Risk**	**Low Risk**
Aphid forecast	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Resistant variety	Yes	Yes	Yes	No	No	Yes	No	No
Imidacloprid seed treatment	Yes	Yes	Yes	No	No	Yes	No	No
Metarhizium	Yes	Yes	No	No	No	Yes	No	No

TABLE 13. Results of integrated pest management systems experiments done in 1996 (Aphid score = index of aphid infestation, higher scores indicate higher infestation; % >450 g = % of lettuce heads exceeding 450 g in weight, %F&UB = % of firm and unblemished heads, n.s. = no significant difference between treatments; 'Managed timing' = up to 2 applications made per week).

a) Experiment 1 - Wellesbourne

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	No	-	-	0.65	0.44	45.9	65.5	69.2	43.8
1B	Saladin	Pirimicarb	Nil	No	Yes	No	0.45	0.52	53.9	60.7	74.2	49.3
1C	Robinson	Triazamate	Nil	No	No	Yes	0.17	0.00	64.3	100.0	72.1	55.4
1D	Robinson	Triazamate	Imidacloprid	No	No	Yes	0.25	0.00	62.5	100.0	83.9	59.8
1E	Saladin	Triazamate	Imidacloprid	Yes	No	Yes	0.40	0.00	51.5	100.0	49.6	5.5
						F ratio:	3.02	7.79	1.61	29.85	6.48	54.33
						Significance (*P*):	n.s.	0.007	n.s.	<0.001	0.013	<0.001
						S.E.D.	0.152	0.138	8.55	3.86	6.98	4.16

b) Experiment 1 - Lancashire

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	No	-	-	5.01	2.89	0.0	5.7	*	11.8
1B	Saladin	Pirimicarb	Nil	No	Yes	No	4.95	2.21	0.0	13.1	*	9.8
1C	Robinson	Triazamate	Nil	No	No	Yes	0.24	0.00	61.4	100.0	*	40.1
1D	Robinson	Triazamate	Imidacloprid	No	No	Yes	0.19	0.00	68.5	100.0	*	25.4
1E	Saladin	Triazamate	Imidacloprid	Yes	No	Yes	0.26	0.00	61.4	100.0	*	21.2
						F ratio:	246	54.36	69.19	199.23	*	5.35
						Significance (*P*):	<0.001	<0.001	<0.001	<0.001	*	0.010
						S.E.D.:	0.235	0.272	5.96	4.43	*	7.43

TABLE 13 (contd.). Results of integrated pest management systems experiments done in 1996.

c) Experiment 2 - Wellesbourne

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	Variety	Foliar	Seed	*Metarhizium*	Routine	Managed	Top	Root	Top	Root	% >450 g	% F&UB
2A	Saladin	Nil	Nil	No	-	-	0.20	0.01	75.0	87.9	78.3	57.9
2B	Saladin	Pirimicarb	Nil	No	Yes	No	0.13	0.03	73.8	87.9	71.4	55.3
2C	Saladin	Triazamate	Nil	No	No	Yes	0.11	0.00	74.4	100.0	72.9	55.4
						F ratio:	0.56	1.00	0.03	1.00	0.79	0.83
						Significance (*P*):	n.s.	n.s.	n.s.	n.s.	n.s	n.s
						S.E.D.:	0.090	0.018	4.99	1.758	5.80	2.26

d) Experiment 2 - Kirton

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	Variety	Foliar	Seed	*Metarhizium*	Routine	Managed	Top	Root	Top	Root	% >450 g	% F&UB
2A	Saladin	Nil	Nil	No	-	-	2.15	2.07	20.2	34.0	48.5	32.6
2B	Saladin	Pirimicarb	Nil	No	Yes	No	1.48	0.93	35.6	51.7	59.8	35.4
2C	Saladin	Triazamate	Nil	No	No	Yes	0.34	0.01	62.2	87.8	69.4	34.5
						F ratio:	67	62.30	104.09	89.66	56.11	0.26
						Significance (*P*):	<0.001	<0.001	<0.001	<0.001	<0.001	n.s
						S.E.D.:	0.158	0.185	2.95	4.10	1.97	3.91

TABLE 13 (contd.). Results of integrated pest management systems experiments done in 1996.

e) Experiment 3 - Wellesbourne

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
3A	Saladin	Nil	Nil	No	-	-	0.30	0.00	66.2	90.0	46.2	45.1
3B	Saladin	Pirimicarb	Nil	No	Yes	No	0.06	0.00	77.7	90.0	46.5	45.6
3C	T139	Triazamate	Nil	No	No	Yes	0.05	0.00	80.0	90.0	41.0	41.9
3D	Saladin	Triazamate	Imidacloprid	No	No	Yes	0.00	0.00	87.9	90.0	36.0	33.5
						F ratio:	9.12	-	7.12	-	3.69	2.03
						Significance (*P*):	0.004	-	0.009	-	n.s.	n.s
						S.E.D.:	0.063	-	4.75	-	3.66	5.56

f) Experiment 3 - Lancashire

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
3A	Saladin	Nil	Nil	No	-	-	2.99	0.10	15.0	82.2	*	39.1
3B	Saladin	Pirimicarb	Nil	No	Yes	No	1.12	0.07	46.5	80.6	*	44.9
3C	T139	Triazamate	Nil	No	No	Yes	0.82	0.00	51.7	100.0	*	8.5
3D	Saladin	Triazamate	Imidacloprid	No	No	Yes	0.25	0.00	69.6	100.0	*	11.2
						F ratio:	62.8	1.27	46.72	1.79	*	'5.46
						Significance (*P*):	<0.001	n.s.	<0.001	n.s.	*	<0.001
						S.E.D.:	0.212	0.061	4.70	5.42	*	6.74

TABLE 13 (contd.). Results of integrated pest management systems experiments done in 1996

g) Experiment 3 - Kirton

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
3A	Saladin	Nil	Nil	No	-	-	0.27	0.13	75.2	79.6	2.5	13.3
3B	Saladin	Pirimicarb	Nil	No	Yes	No	0.15	0.13	79.5	80.6	2.2	20.3
3C	T139	Triazamate	Nil	No	No	Yes	0.01	0.00	89.4	100.0	4.8	23.3
3D	Saladin	Triazamate	Imidacloprid	No	No	Yes	0.00	0.00	89.7	100.0	5.2	21.0
						F ratio:	7.87	3.27	11.20	4.15	0.59	4.78
						Significance (*P*):	0.01	n.s.	0.002	0.042	n.s.	0.029
						S.E.D.:	0.064	0.055	3.08	3.85	2.86	2.79

TABLE 14. Results of integrated pest management systems experiments done in 1997 (see Table 2 legend for explanation of headings; 'Managed Timing' treatments triggered by the presence of wingless aphids only in Experiment 1, x1 pw = **up to** one application made per week, x2 pw = **up to** 2 applications made per week).

a) Experiment 1 - Lancashire

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	No	-	-	1.52	3.133	29.9	12.3	79.4	43.6
1B	Saladin	Pirimicarb	Nil	No	Yes	No	1.85	2.68	35.3	13.7	100.0	45.5
1C	Saladin	Triazamate	Nil	Yes	No	Yes, x2 pw	0.15	0.00	72.0	100.0	100.0	53.2
1D	Saladin	Triazamate	Nil	Yes	No	Yes, x1 pw	0.47	0.07	58.5	82.4	100.0	47.4
1E	Saladin	Triazamate	Imidacloprid	Yes	No	Yes, x2 pw	0.23	0.00	69.2	100.0	78.1	56.8
1F	Saladin	Triazamate	Imidacloprid	Yes	No	Yes, x1 pw	0.15	0.08	73.5	75.2	100.0	47.4
						F ratio:	15.39	527.17	23.28	146.91	2.41	2.59
						Significance (*P*):	<0.001	<0.001	<0.001	<0.001	n.s.	n.s.
						S.E.D.	0.426	0.145	8.58	6.80	5.14	4.88

b) Experiment 1 - Wellesbourne

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	No	-	-	0.267	0.183	70.3	73.8	81.7	37.8
1B	Saladin	Pirimicarb	Nil	No	Yes	No	0.00	0.02	100.0	85.7	77.0	42.1
1C	Saladin	Triazamate	Nil	Yes	No	Yes, x2 pw	0.02	0.00	85.7	100.0	76.2	44.0
1D	Saladin	Triazamate	Nil	Yes	No	Yes, x1 pw	0.00	0.02	100.0	85.7	75.1	44.5
1E	Saladin	Triazamate	Imidacloprid	Yes	No	Yes, x2 pw	0.00	0.00	100.0	100.0	80.1	45.5
1F	Saladin	Triazamate	Imidacloprid	Yes	No	Yes, x1 pw	0.000	0.00	100.0	100.0	79.6	46.0
						F ratio:	4.36	6.47	6.02	11.27	0.27	1.74
						Significance (*P*):	0.044	0.016	0.019	0.003	n.s.	n.s.
						S.E.D.	0.115	0.064	7.01	4.03	7.19	4.99

TABLE 14(contd.). Results of integrated pest management systems experiments done in 1997.

d) Experiment 1 - Kirton

		Insecticide			Timing		Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	***Metarhizium***	**Routine**	**Managed**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	No	-	-	0.37	3.79	62.0	18.5	49.4	10.7
1B	Saladin	Pirimicarb	Nil	No	Yes	No	0.06	1.48	85.5	38.2	66.2	26.3
1C	Saladin	Triazamate	Nil	Yes	No	Yes, x2 pw	0.02	0.09	85.7	82.2	68.5	23.0
1D	Saladin	Triazamate	Nil	Yes	No	Yes, x1 pw	0.00	0.21	100.0	75.3	79.1	19.4
1E	Saladin	Triazamate	Imidacloprid	Yes	No	Yes, x2 pw	0.00	0.00	100.0	100.0	74.4	33.1
1F	Saladin	Triazamate	Imidacloprid	Yes	No	Yes, x1 pw	0.00	0.00	100.0	100.0	66.0	25.9
						F ratio:	3.8	29.53	9.3	40.65	8.42	3.07
						Significance (*P*):	n.s.	<0.001	0.005	<0.001	0.007	n.s.
						S.E.D.	0.16620	0.622	7.92	10.38	6.98	7.73

e) Experiment 2 - Lancashire

		Insecticide		Timing			Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	**Routine**	**Managed**	**Trigger**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	-	-	-	1.48	1.00	42.8	56.0	64.0	53.8
1B	Saladin	Pirimicarb	Nil	Yes	No	-	0.25	0.37	71.1	67.0	66.6	54.8
1C	Saladin	Triazamate	Nil	No	Yes, x2 pw	Wingless	0.05	0.02	85.7	85.7	76.1	67.6
1D	Saladin	Triazamate	Nil	No	Yes, x1 pw	Wingless	0.58	0.02	54.4	85.7	68.4	59.2
1E	Saladin	Triazamate	Nil	No	Yes, x2 pw	Any aphid	0.40	0.00	64.7	100.0	66.8	63.9
1F	Saladin	Triazamate	Nil	No	Yes, x1 pw	Any aphid	0.05	0.00	79.5	100.0	75.6	66.4
						F ratio:	10.78	38.28	7.92	35.36	1.27	3.84
						Significance (*P*):	0.003	<0.001	0.009	<0.001	n.s.	n.s.
						S.E.D.	0.338	0.145	9.18	5.28	6.73	5.9

TABLE 14 (contd.). Results of integrated pest management systems experiments done in 1997.

f) Experiment 2 - Kirton

		Insecticide		Timing			Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	**Routine**	**Managed**	**Trigger**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	-	-	-	0.06	3.70	83.5	13.2	18.4	3.3
1B	Saladin	Pirimicarb	Nil	Yes	No	-	0.00	0.44	100.0	66.3	26.7	21.2
1C	Saladin	Triazamate	Nil	No	Yes, x2 pw	Wingless	0.03	0.35	81.4	66.1	23.7	21.0
1D	Saladin	Triazamate	Nil	No	Yes, x1 pw	Wingless	0.03	0.30	81.4	63.2	35.8	28.1
1E	Saladin	Triazamate	Nil	No	Yes, x2 pw	Any aphid	0.00	0.16	100.0	68.9	32.3	22.6
1F	Saladin	Triazamate	Nil	No	Yes, x1 pw	Any aphid	0.03	0.83	83.9	50.0	21.4	25.8
						F ratio:	0.840	153.07	0.70	14.20	0.69	7.23
						Significance (*P*):	n.s.	<0.001	n.s.	0.001	n.s.	0.011
						S.E.D.	0.043	0.242	6.57	12.10	10.71	7.02

g) Experiment 2 - Wellesbourne

		Insecticide		Timing			Aphid score		% plants aphid-free		Produce quality	
Code	**Variety**	**Foliar**	**Seed**	**Routine**	**Managed**	**Trigger**	**Top**	**Root**	**Top**	**Root**	**% >450 g**	**% F&UB**
1A	Saladin	Nil	Nil	-	-	-	0.00	0.02	100.0	85.7	84.7	29.2
1B	Saladin	Pirimicarb	Nil	Yes	No	-	0.00	0.00	100.0	100.0	83.9	23.2
1C	Saladin	Triazamate	Nil	No	Yes, x2 pw	Wingless	0.02	0.00	85.7	100.0	87.0	27.0
1D	Saladin	Triazamate	Nil	No	Yes, x1 pw	Wingless	0.02	0.00	85.7	100.0	76.3	21.8
1E	Saladin	Triazamate	Nil	No	Yes, x2 pw	Any aphid	0.00	0.00	100.0	100.0	100.0	24.8
1F	Saladin	Triazamate	Nil	No	Yes, x1 pw	Any aphid	0.00	0.00	100.0	100.0	82.7	28.0
						F ratio:	0.450	2.500	0.450	2.50	0.03	0.8
						Significance (*P*):	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
						S.E.D.	0.143	0.010	3.69	2.49	4.14	4.89

TABLE 15. Articles, scientific papers and talks presenting the finding of research from the project.

Scientific presentations

ELLIS, P.R. Integrated pest management of aphids on outdoor lettuce crops. IOBC/WPRS meeting on Integrated Control in Field Vegetable Crops 6-8 November 1995.

ELLIS, P.R. Integrated pest management of aphids on outdoor lettuce crops. BCPC Symposium – Integrated Crop Protection: towards sustainability? 11-14 September 1995.

PICKETT, J. Novel approaches for the study and exploitation of semio-chemically-mediated interactions between insects and their hosts. Max-Planck-Institut fur Verhaltenphysiologie, Seewiesen, 2 May 1996.

CHANDLER, D. Biocontrol of *Pemphigus bursarius* with *Metarhizium* and host plant resistance. Verbal presentation to Annual Meeting of British Mycological Society Invertebrate Mycopathology Working Group, Wellesbourne, 2 October 1996.

PICKETT, J. Insect Supersense: Mate and Host Location by Insects as Model Systems for Exploiting Olfactory Interactions. Unilever, Colworth House, 22 January 1997.

CHANDLER, D. Use of insect pathogens for organic farming. Verbal presentation to Welsh Pest Management Forum meeting 'New techniques of pest control in organic farming', Cardiff, 26 March 1997.

COLLIER, R.H. Development of integrated pest management systems for field vegetable crops. BCPC Symposium - Crop Protection and Food Quality: Meeting Customer Needs. 16-19 September 1997.

COLLIER, R.H. IOBC/WPRS meeting on Integrated Control in Field Vegetable Crops 6-9 October 1997.

ELLIS, P.R., TATCHELL, G.M., COLLIER, R.H., CHANDLER, D.,MEAD, A.,JUKES, P.L.,VICE,.W.E., PARKER, W.E. & WADHAMS, L.J.(1995). Integrated pest management of aphids on outdoor lettuce crops. Integrated Crop Protection: Towards sustainability? BCPC Symposium Proceedings No **63**, pp. 115-122.

ELLIS, P.R., TATCHELL, G.M., COLLIER, R.H., & PARKER, W.E. (1996). Integrated pest management of aphids on outdoor lettuce crops. Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin 1996, **19**, (11), 91-97.

PARKER, W.E. & BLOOD-SMYTH, J.A. (1996). Insecticidal control of foliar and root aphids on outdoor lettuce. Proceedings of the Brighton Crop Protection Conference – Pests and Diseases 3, pp. 861-866.

COLLIER, R.H. (1997). Development of integrated pest management systems for field vegetable crops. Crop Protection and Food Quality: Meeting Customer Needs. BCPC Symposium, University of Kent, 17-19 September 1997, pp.473-478.

CHANDLER, D. (1997). Selection of an isolate of the insect pathogenic fungus *Metarhizium anisopliae* virulent to the lettuce root aphid, *Pemphigus bursarius*. Biocontrol Science and Technology, **7**, 95-104.

COLLIER, R.H. *et al.* (1998). Strategies for the control of aphid pests of lettuce. Integrated Control in Field Vegetable Crops. IOBC/WPRS Bulletin 1998.

CHANDLER, D. Short news item on the use of *Metarhizium* to control lettuce root aphid in The Times' newspaper (28 April 1997).

The response of the current lettuce aphid, *Nasonovia ribisnigri*, to volatiles from its primary host plant. (Wadhams and Tatchell) *Journal of Chemical Ecology*. In preparation.

Windows of opportunity: predicting the impact of aphid phenology on IPM programmes in sequentially-planted lettuce crops. (Collier and Tatchell) *Bulletin of Entomological Research* or *Environmental Entomology*. In preparation.

An integrated approach to the control of aphids in sequentially-planted lettuce. (Parker, Collier and Tatchell) *Journal of Economic Entomology*, or *Crop Protection*. In preparation.

Articles and reports in farming press

ELLIS, P.R. & TATCHELL, G.M. (1995). Integrated pest management of aphids on outdoor lettuce crops – the way ahead. HDC Project News **32**, May 1995, pp. 4-5.

LONG, E. (1996). Resistant iceberg on the horizon. Grower 18 July 1996, pp. 49-50.

TATCHELL, G. M. & COLLIER, R. H. (1998). New approaches to controlling aphids in lettuce. Vegetable Farmer, May 1998. In press.

TATCHELL, G. M. & COLLIER, R. H. (1998) New opportunities for aphid control in lettuce. The Grower, May 1998. In press.

Demonstrations (plots on farms etc) and talks to growers & consultants

LINK lettuce field experiments day HRI Wellesbourne 8 August 1995

Visit to Trent Valley Growers by LINK lettuce group. 25 September 1996.

BLOOD-SMYTH, J. 1996. Control of lettuce aphids. Jarrow Produce, Ardleigh, Essex, 3 September 1996.

BLOOD-SMYTH, J. 1997. Talk to Tendring growers on pests of field vegetable crops, 3 March, 1997.

CHANDLER. D. 1997. Biologically-based control for organic farming. Verbal presentation to West Mercia Organic Growers forum, HDRA Ryton, 20 January 1997.

PICKETT, J. New opportunities for semiochemical control of vegetable aphids. Vegetable Consultants Association, Oxford, 27 November 1996.

PARKER, W.E. March 1995. ADAS Leafy Salads Project, Center Parcs, Notts.

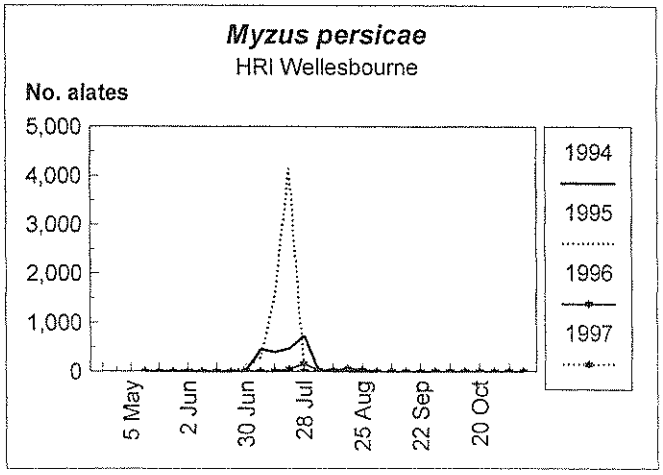
PARKER, W.E. November 1995. ADAS Outdoor Lettuce Conference, Burscough, Lancashire.

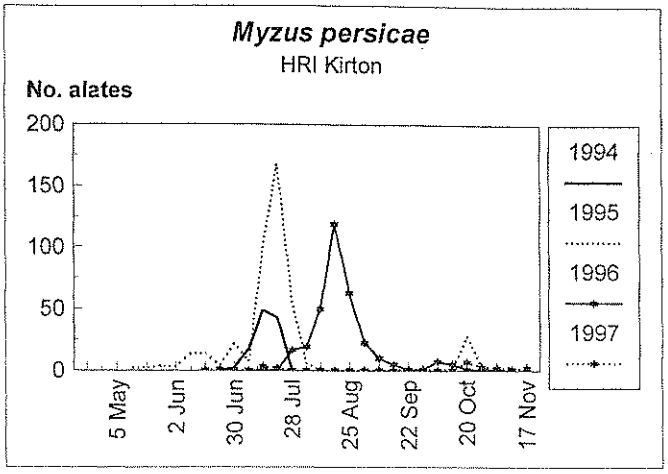
PARKER, W.E. January 1996. Presentation to HDC staff (review of use imidacloprid on lettuce).

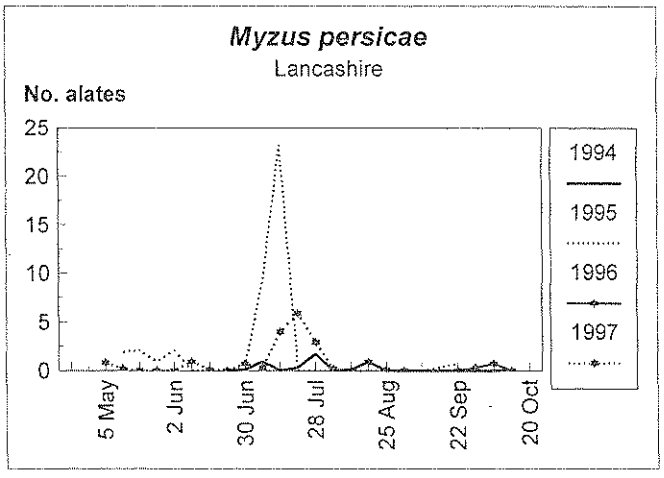
PARKER, W.E. February 1997 ADAS vegetable consultants training day, Gleadthorpe, Notts.

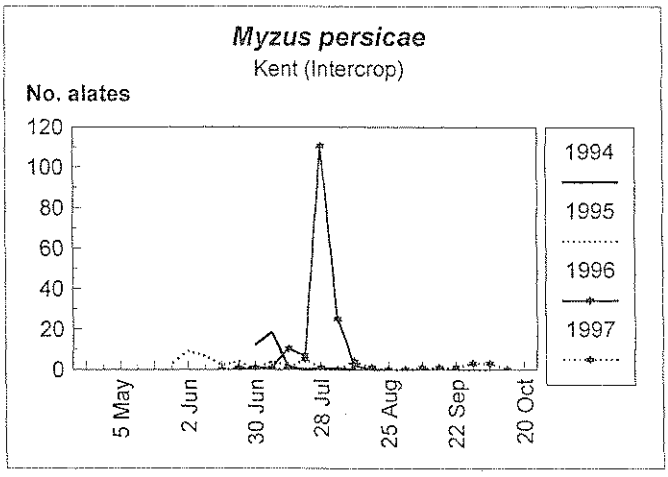
PARKER, W.E. September 1997 ADAS Entomologists Technical meeting, Malvern, Hereford & Worcester.

FIGURE 1 The numbers of *Myzus persicae* recorded in water trap samples from HRI Wellesbourne, HRI Kirton, Lancashire and two sites in Kent, 1994 to 1997.









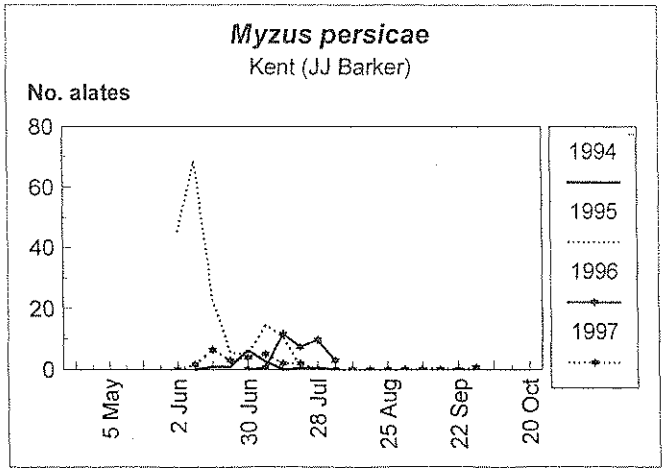
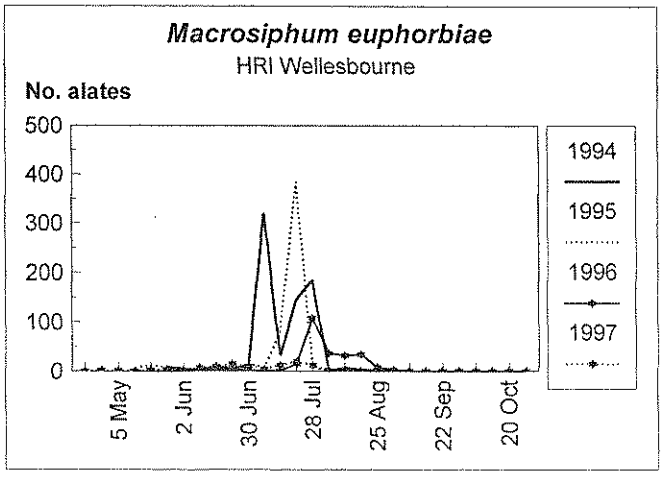
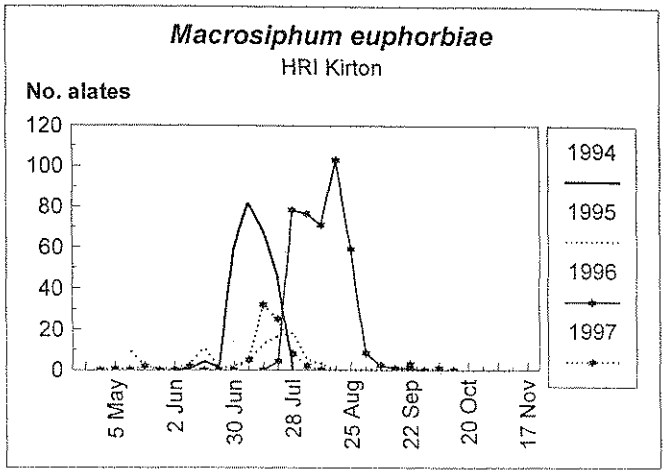
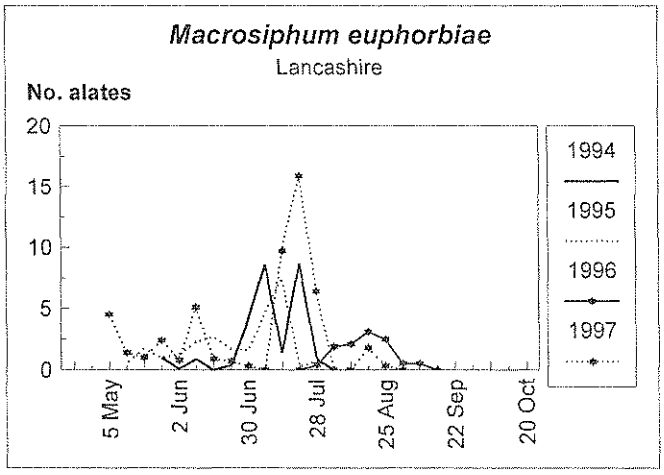
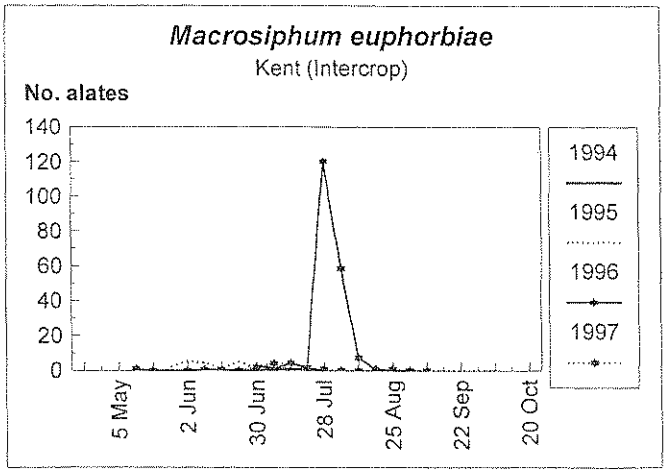


FIGURE 2 The numbers of *Macrosiphium euphorbiae* recorded in water trap samples from HRI Wellesbourne, HRI Kirton, Lancashire and two sites in Kent, 1994 to 1997.









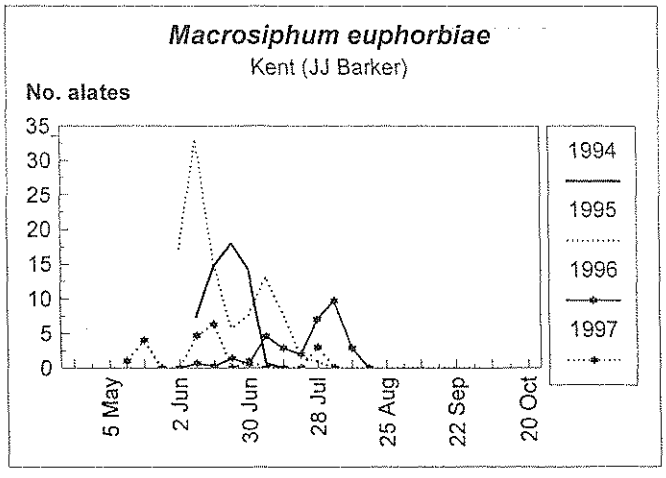
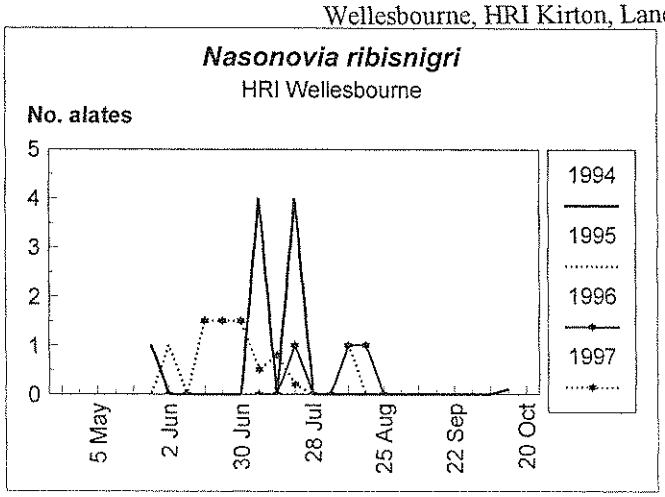
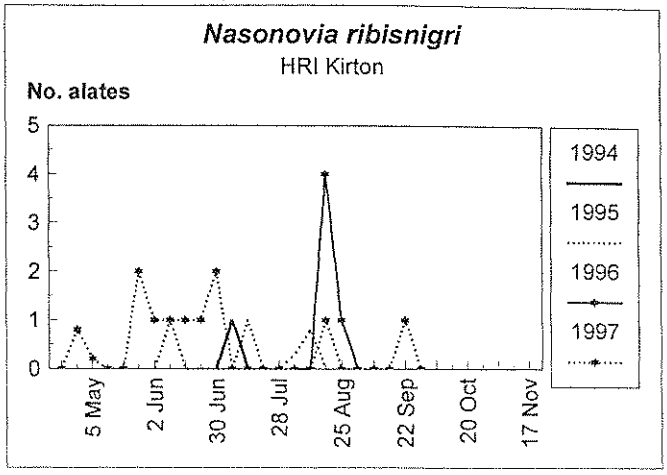
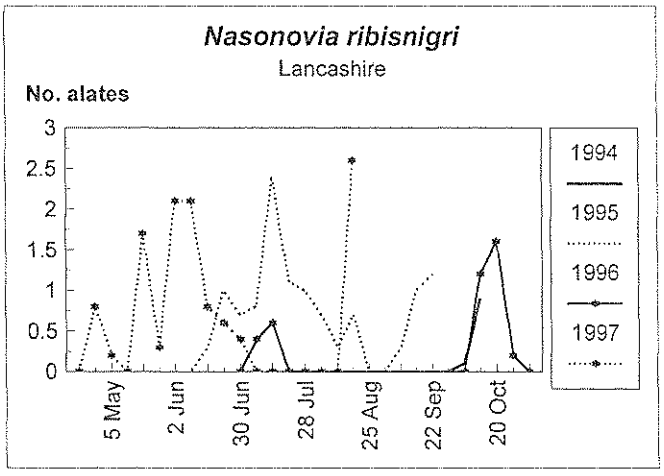
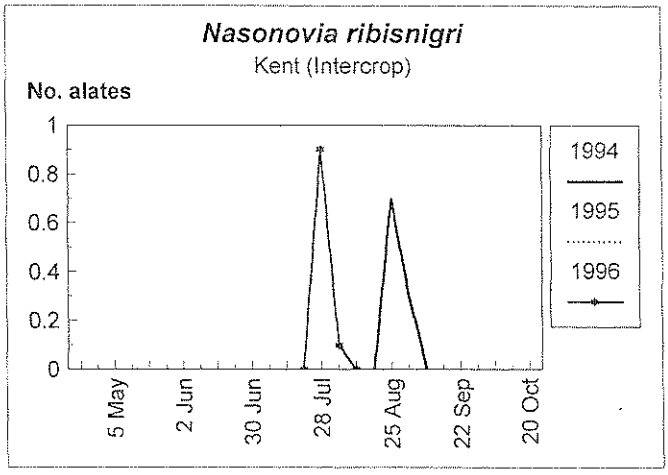


FIGURE 3 The numbers of *Nasonovia ribisnigri* recorded in water trap samples from HRI Wellesbourne, HRI Kirton, Lancashire and two sites in Kent, 1994 to 1997.









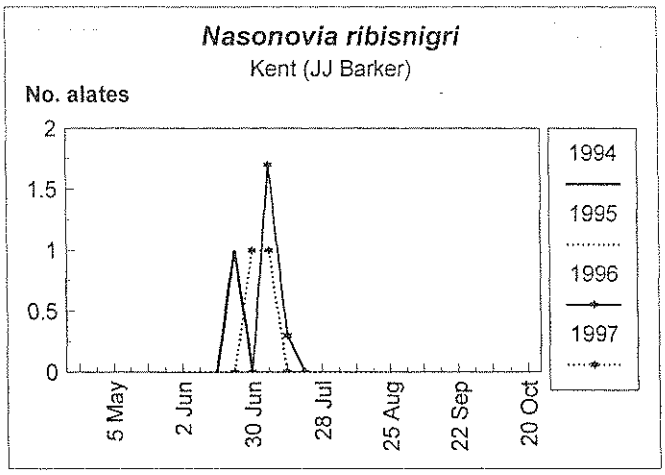
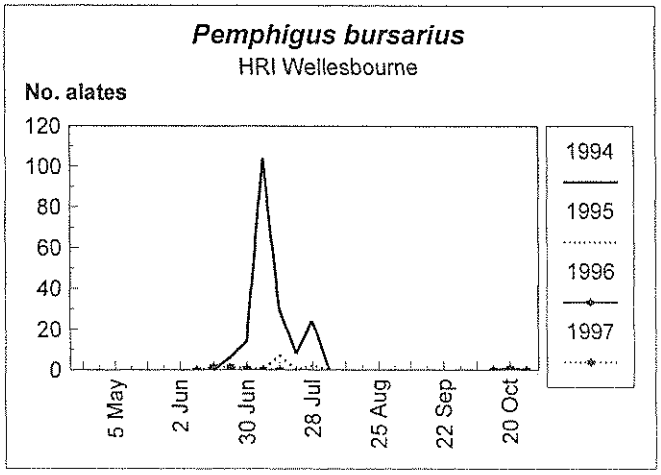
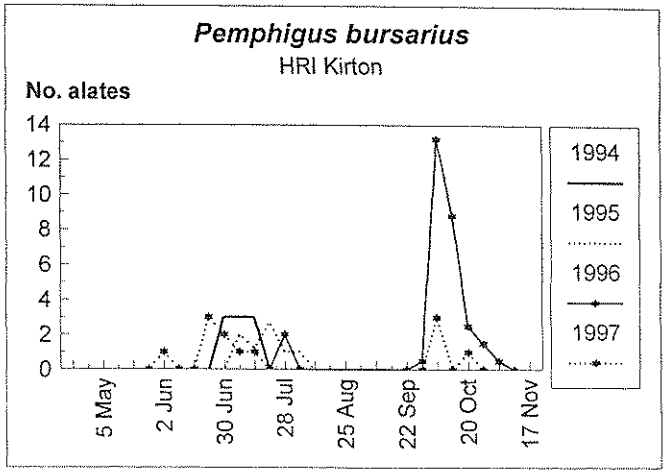
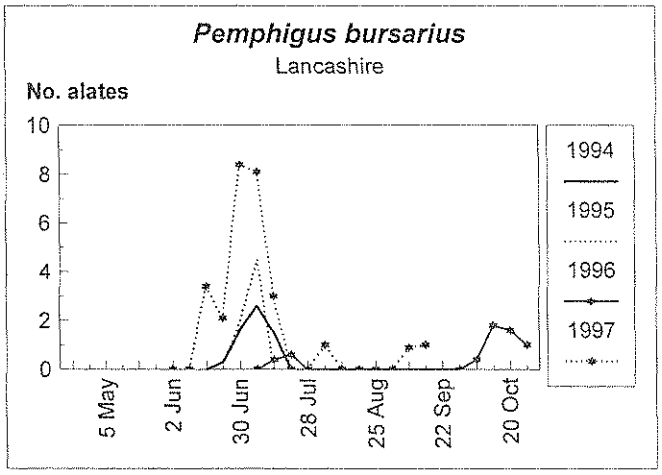
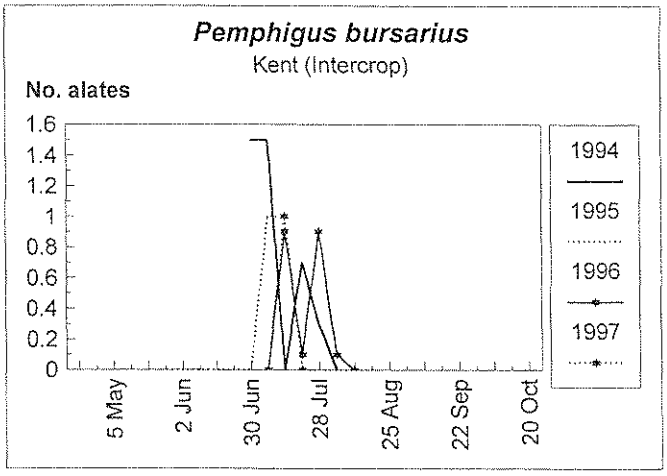


FIGURE 4 The numbers of *Pemphigus bursarius* recorded in water trap samples from HRI Wellesbourne, HRI Kirton, Lancashire and two sites in Kent, 1994 to 1997.









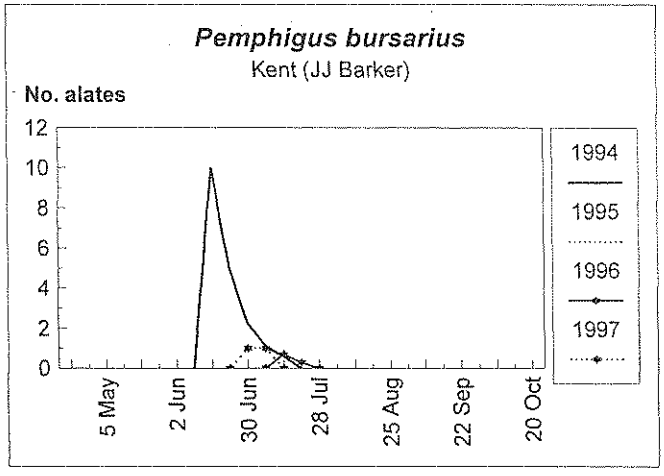
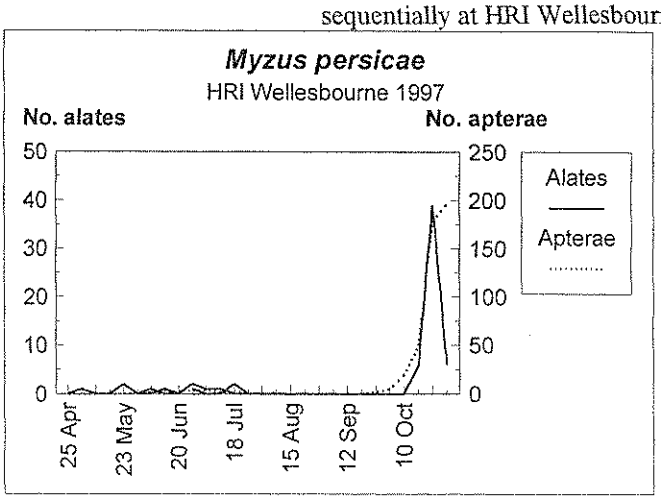
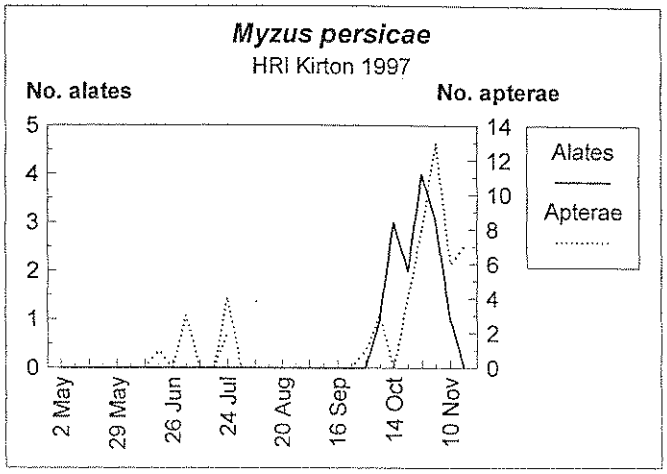


FIGURE 5 The numbers of alate and apterous *Myzus persicae* recorded on plots of lettuce planted sequentially at HRI Wellesbourne, HRI Kirton and in Lancashire, 1997.





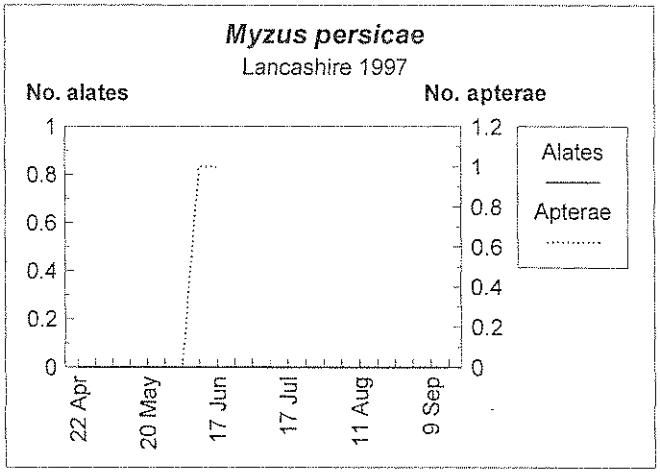
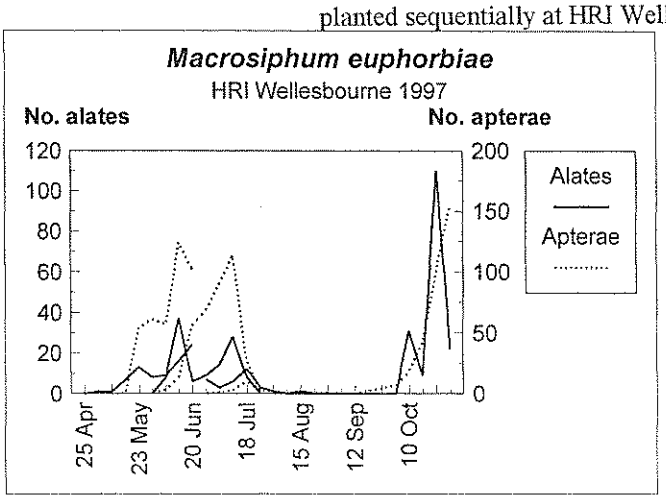
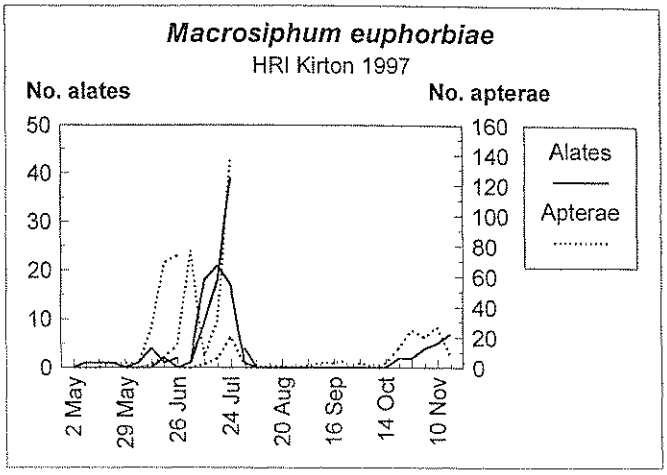


FIGURE 6 The numbers of alate and apterous *Macrosiphum euphorbiae* recorded on plots of lettuce planted sequentially at HRI Wellesbourne, HRI Kirton and in Lancashire, 1997.





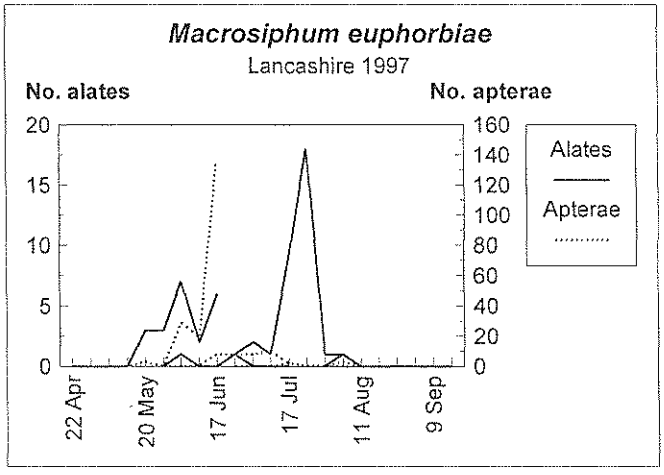
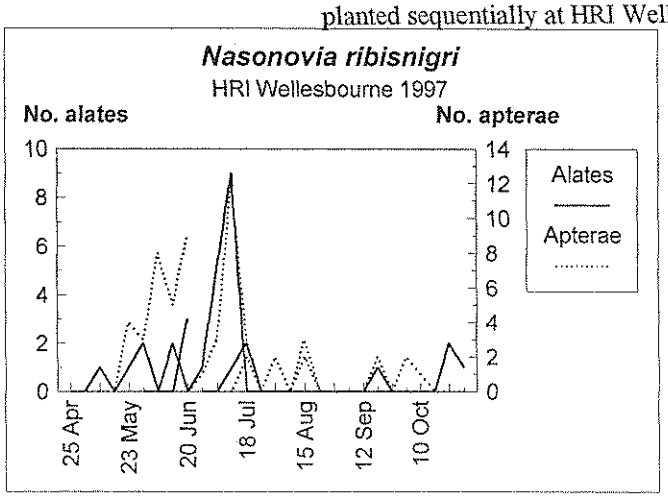
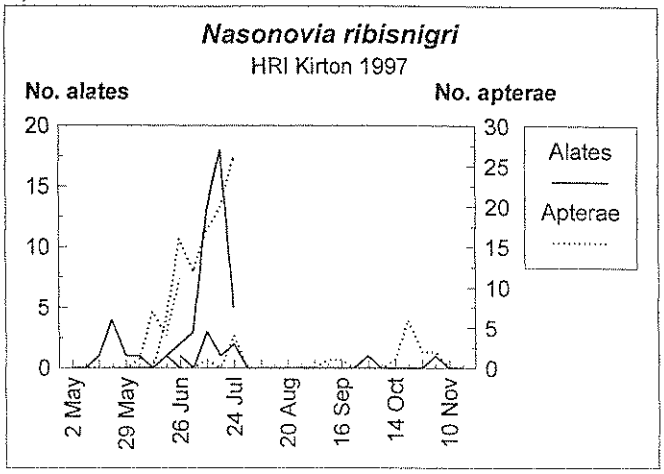


FIGURE 7 The numbers of alate and apterous *Nasonovia ribisnigri* recorded on plots of lettuce planted sequentially at HRI Wellesbourne, HRI Kirton and Lancashire, 1997.





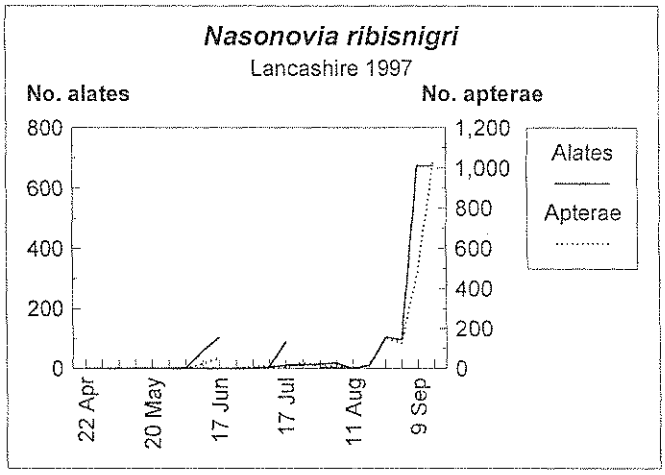
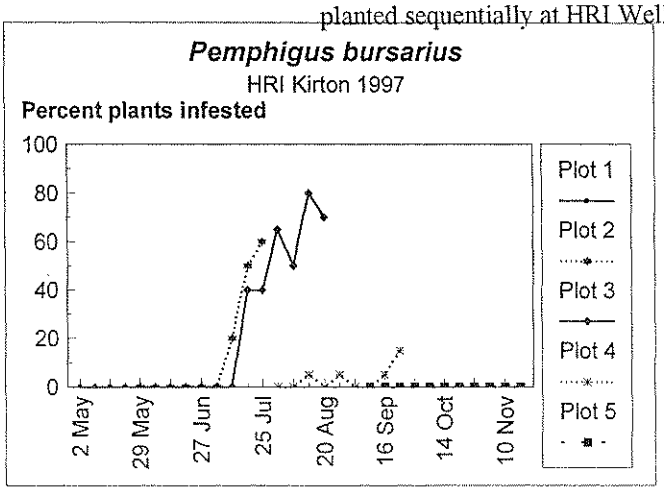
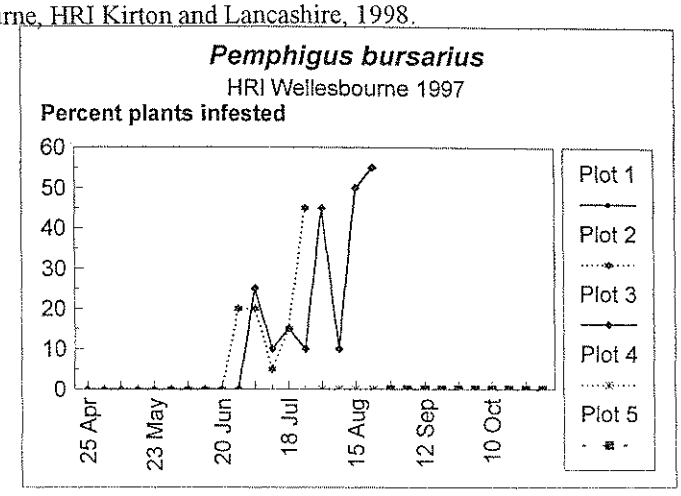


FIGURE 8 The percentage of plants with roots infested with *Pemphigus bursarius* on plots of lettuce planted sequentially at HRI Wellesbourne, HRI Kirton and Lancashire, 1998.





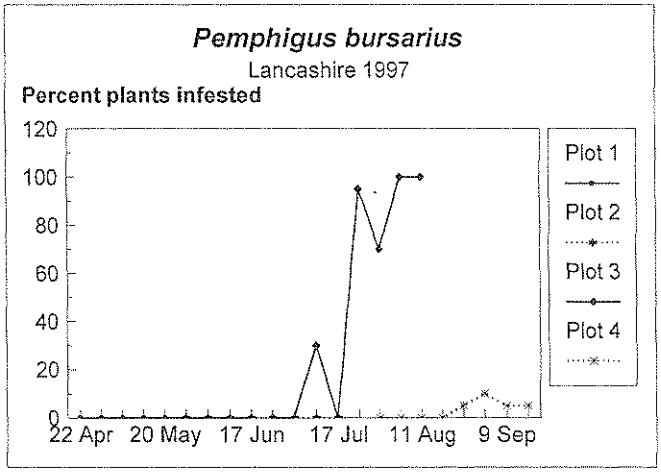


FIGURE 9 The periods of the year when lettuce crops are at risk from aphid infestation to the foliage or roots.

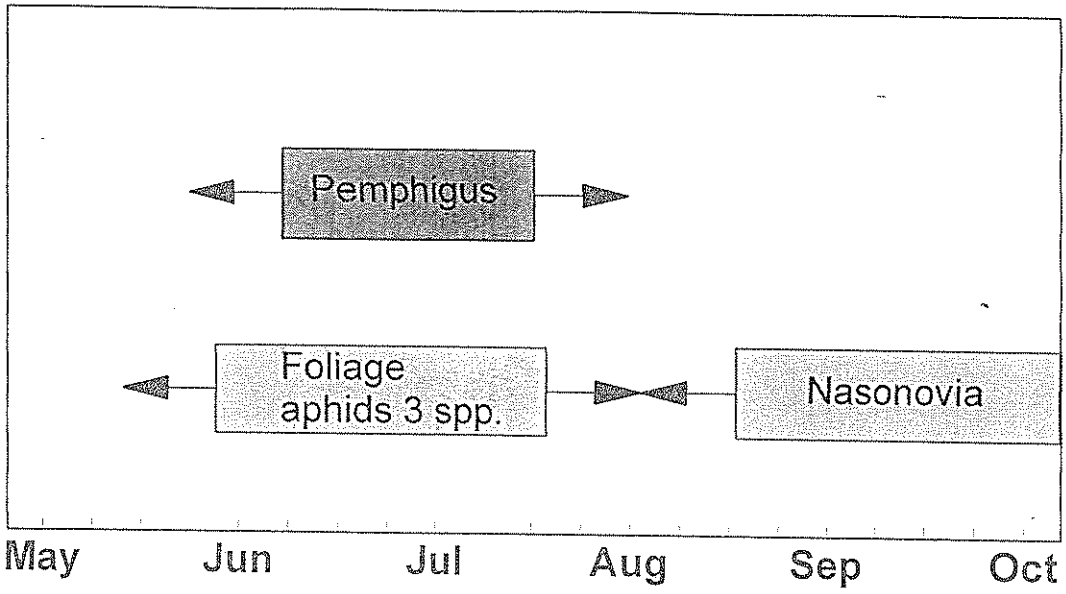
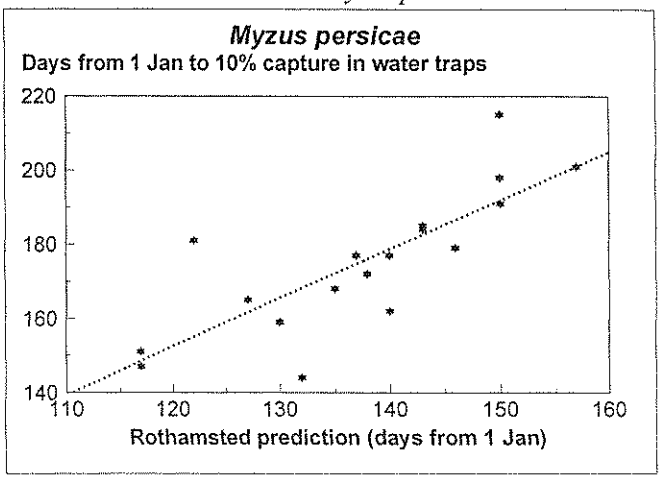
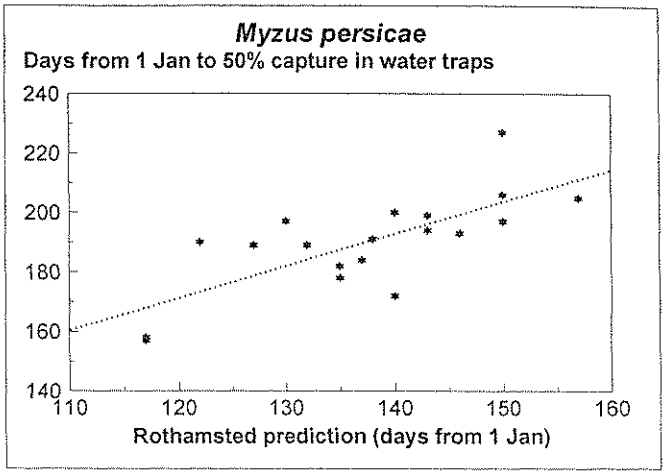
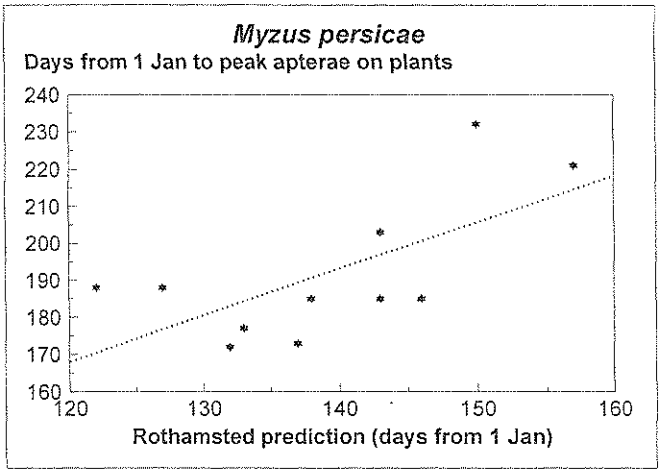


FIGURE 10 Significant relationships for forecasting the colonisation by and population events for *Myzus persicae* on lettuce.







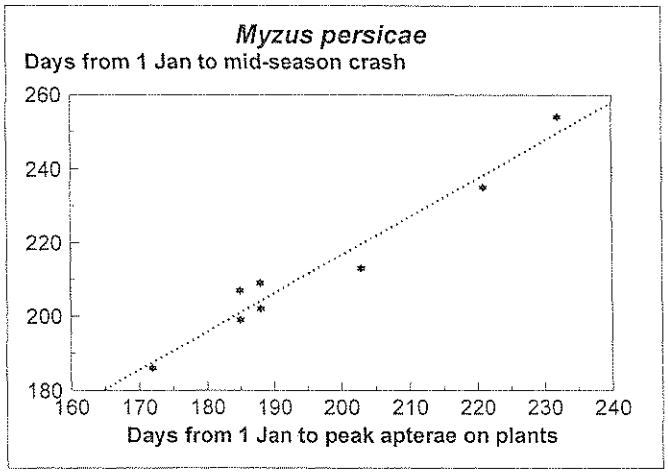
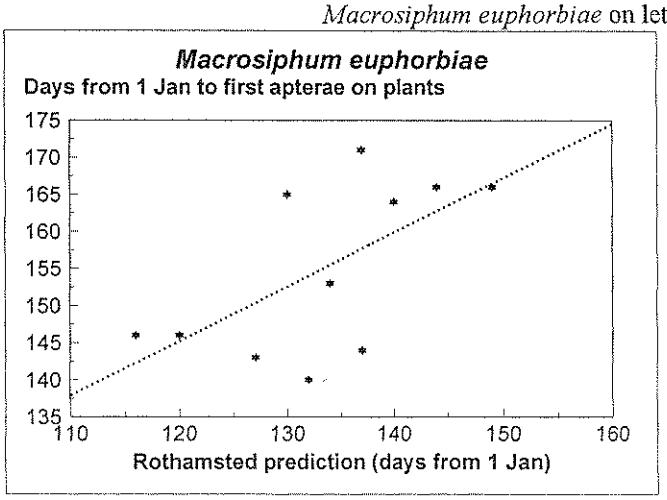
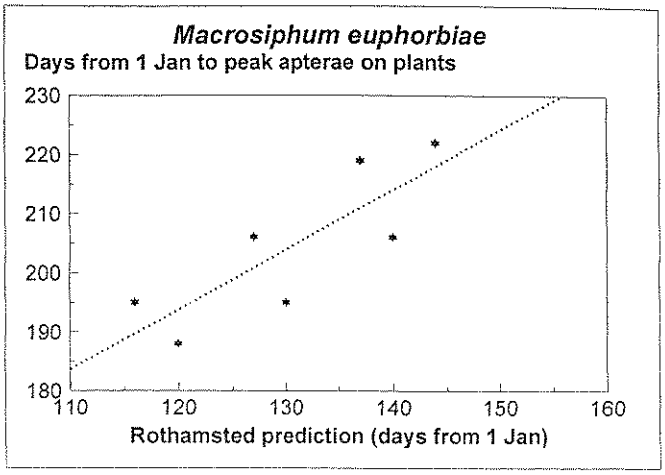


FIGURE 11 Significant relationships for forecasting the colonisation by and population events for *Macrosiphum euphorbiae* on lettuce.





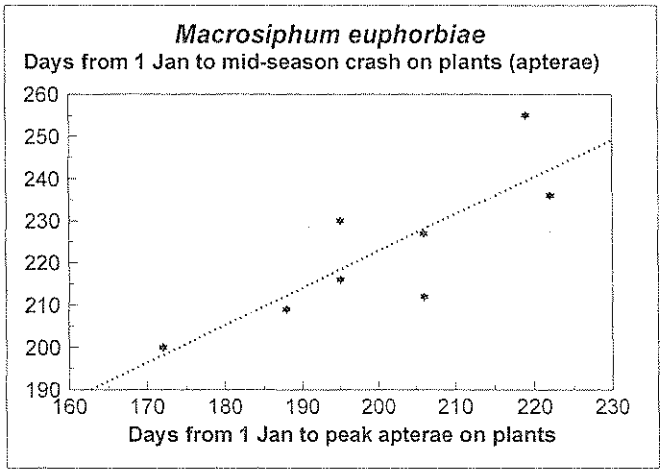
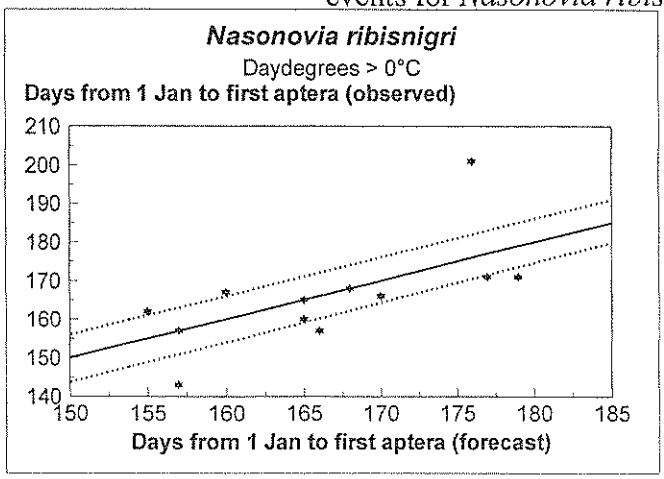
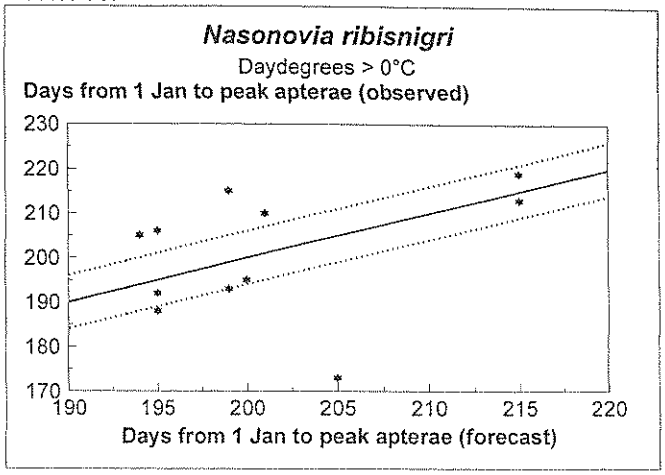
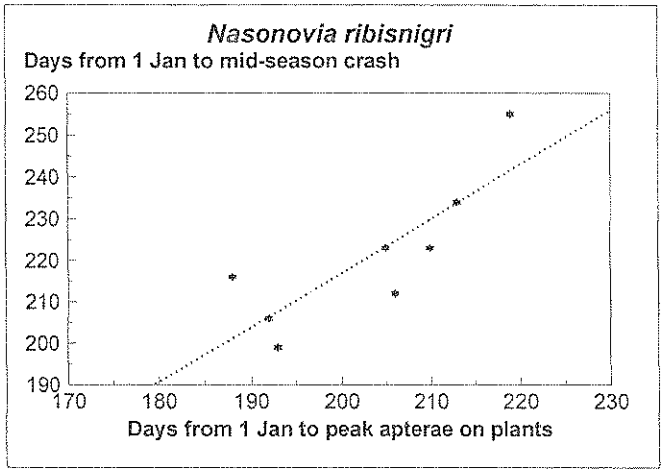


FIGURE 12 Significant relationships for forecasting the colonisation by and population events for *Nasonovia ribisnigri* on lettuce.







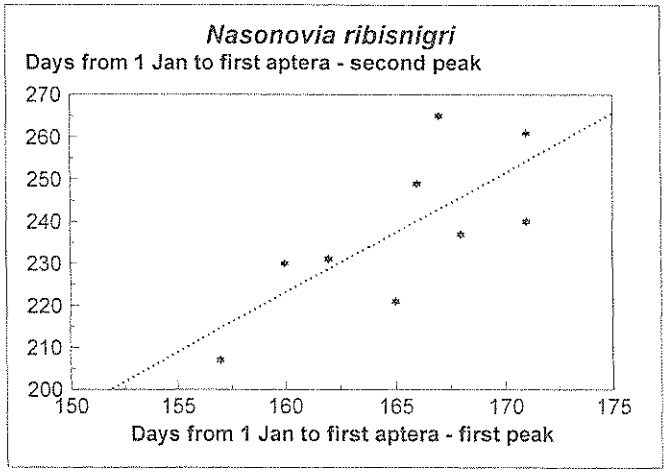
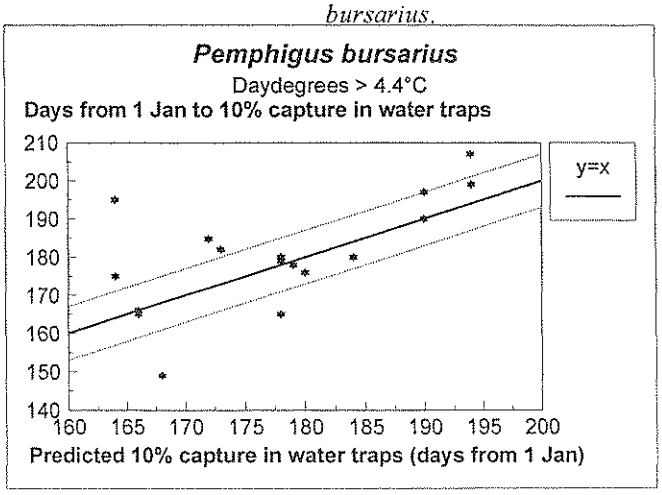
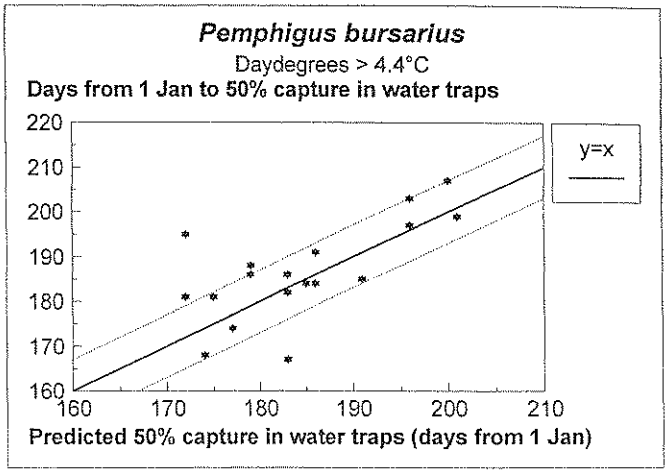


FIGURE 13 Significant relationships for forecasting the colonisation of lettuce by *Pemphigus bursarius*.





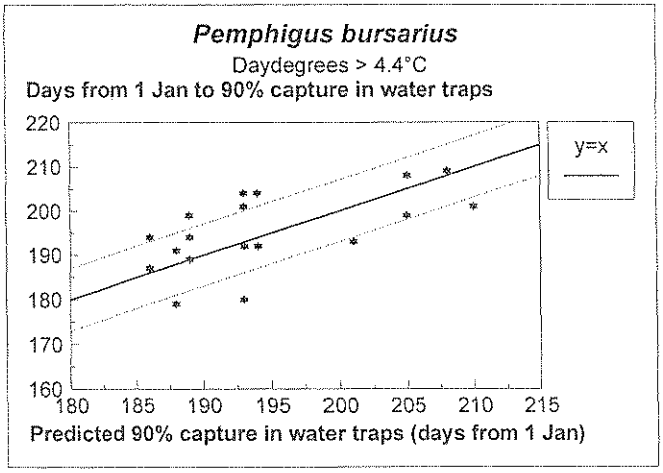


Figure 14 Coupled GC – Single cell recording on *Nasonovia ribisnigri* (proximal primary rhinarium): response to lettuce volatiles.

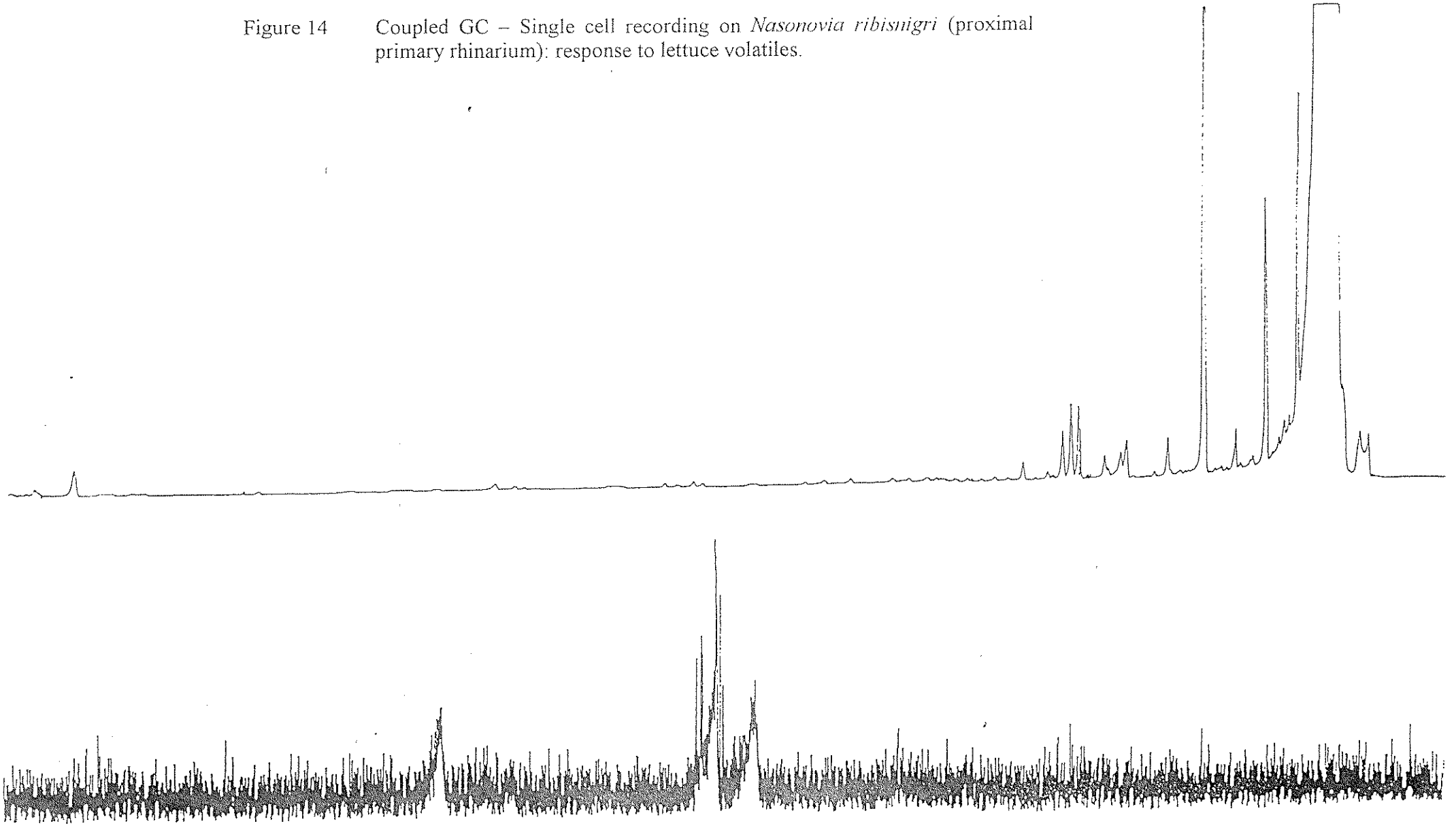


Figure 15 Coupled GC – Electroantennogram on *Nasonovia ribisnigri*: response to blackcurrant volatiles.

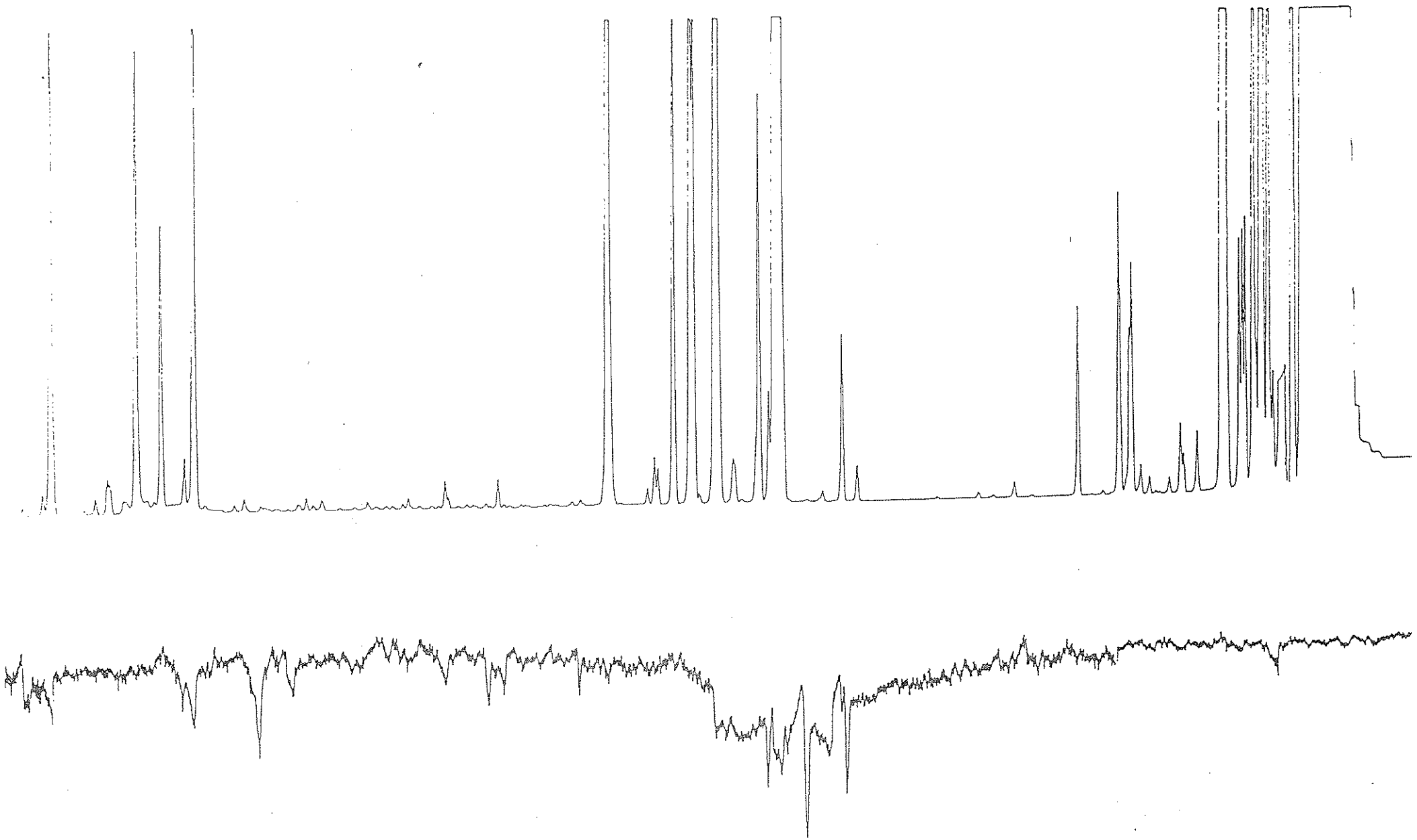


FIGURE 16 The electroantennogram response of *Nasonovia ribisnigri* to synthetic compounds

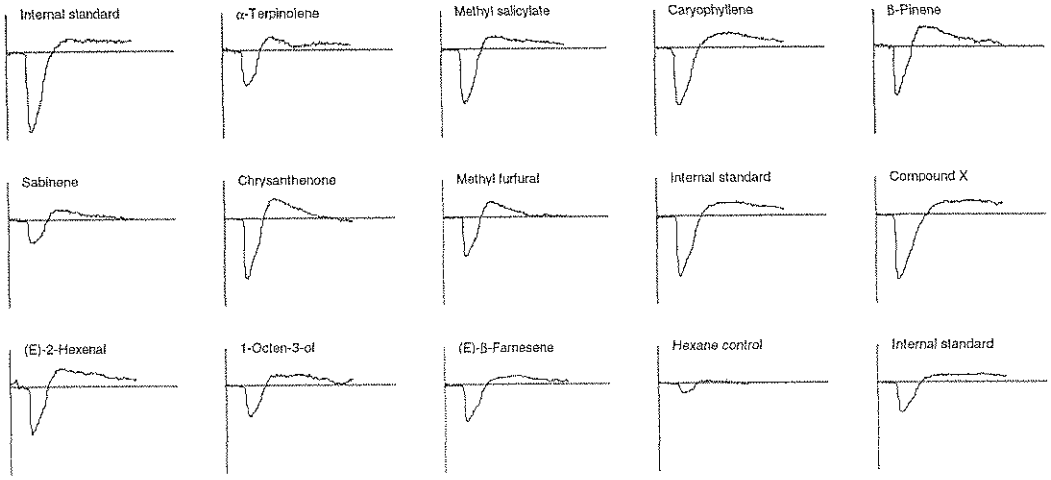


Figure 17 The behavioural response of alate *Nasonovia ribisnigri* to extracts of blackcurrant in the presence or absence of lettuce in an olfactometer.

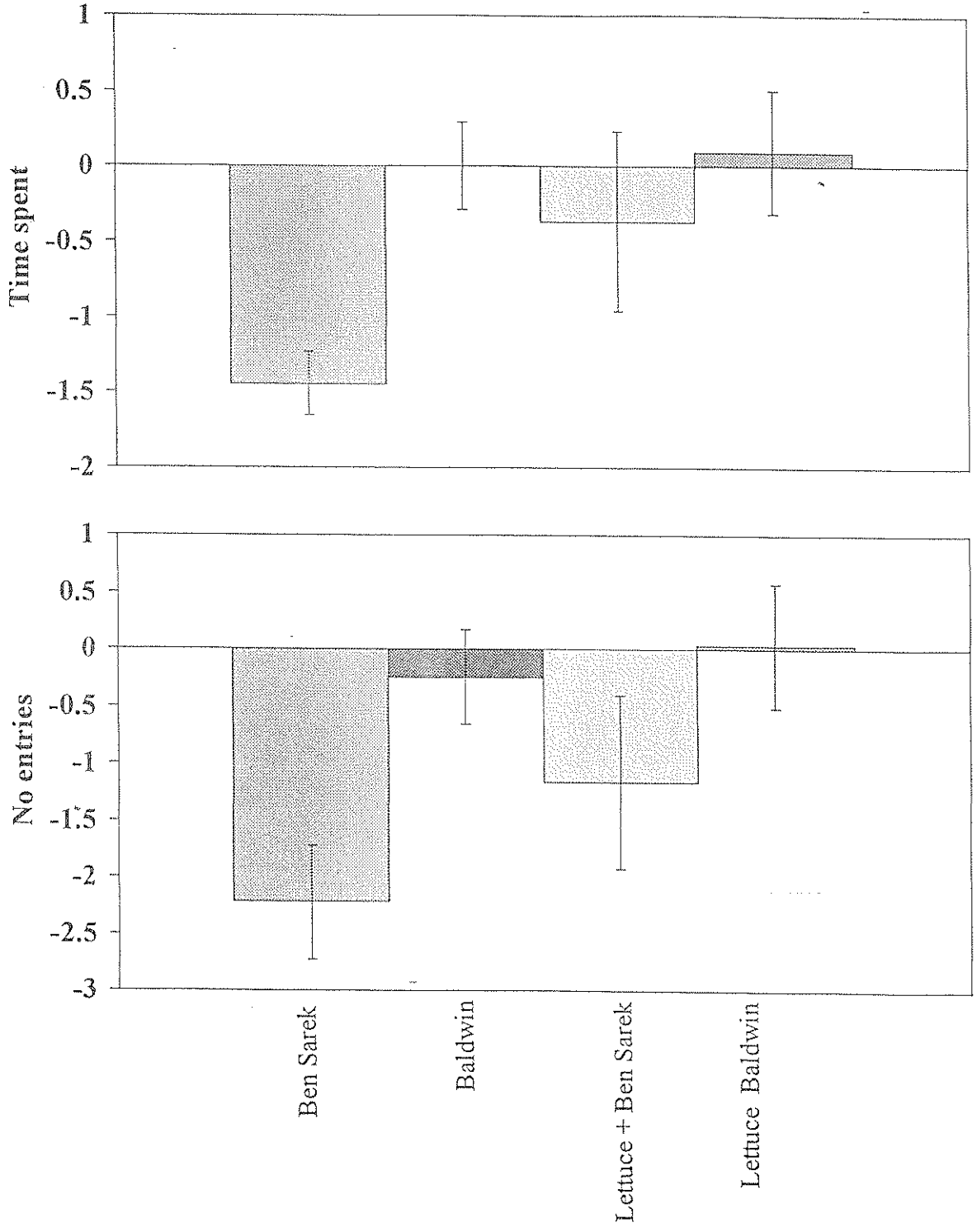


Figure 18 The behavioural response of alate *Nasonovia ribisnigri* to blackcurrant leaf or extract in the presence or absence of lettuce in an olfactometer.

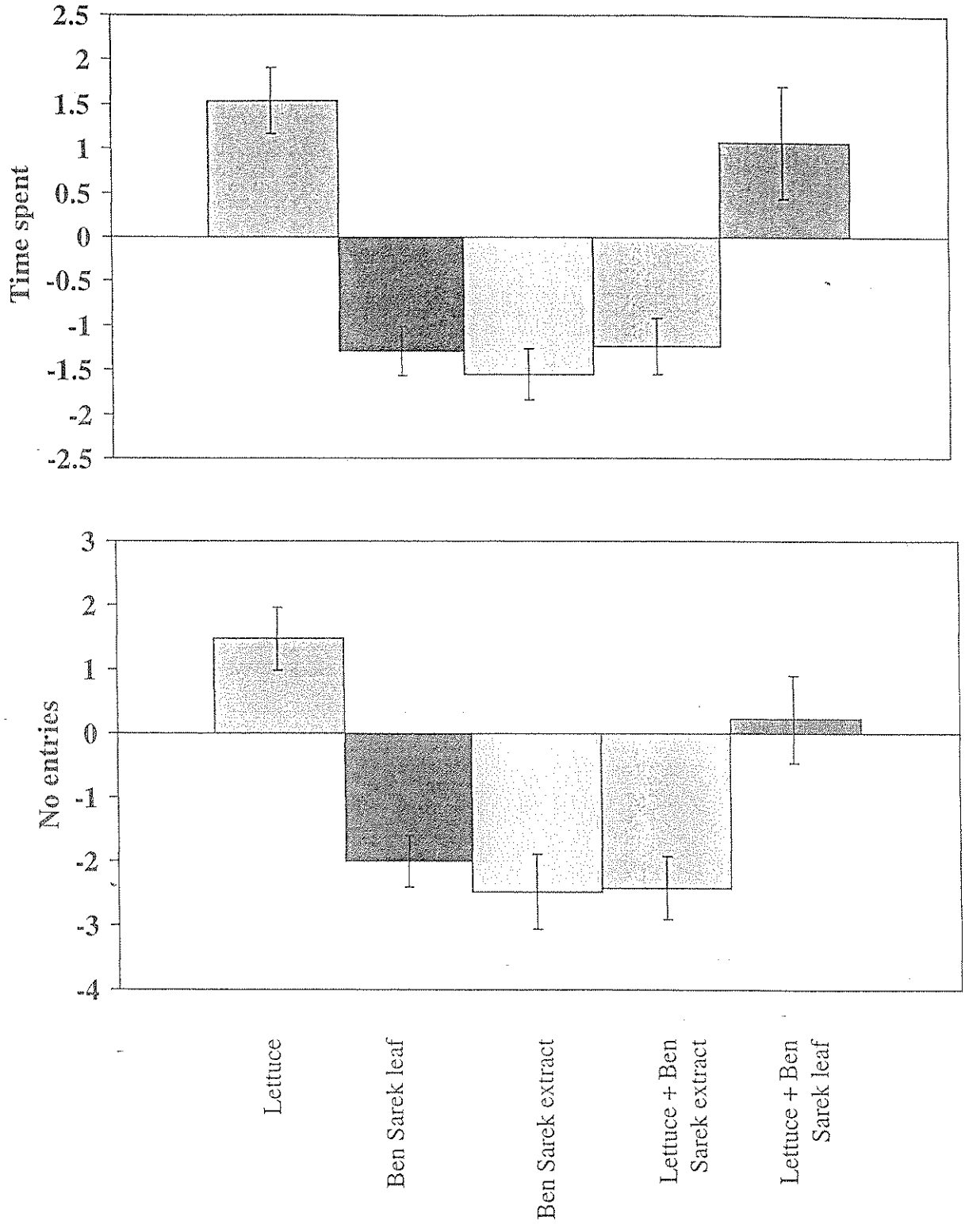


Figure 19 The behavioural response of alate *Nasonovia ribisnigri* to different doses of blackcurrant extract in an olfactometer.

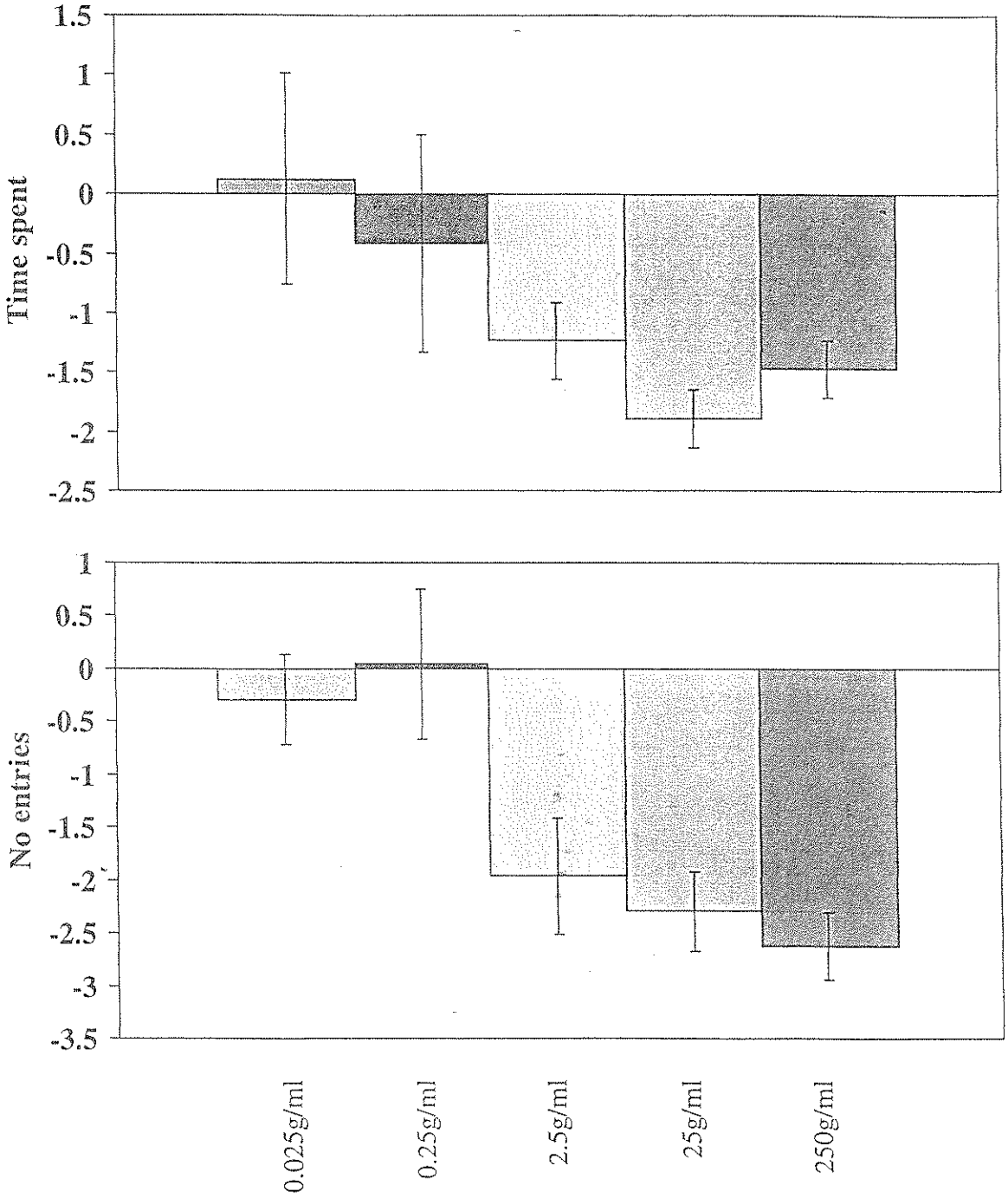


Figure 20 The behavioural response of alate *Nasonovia ribisnigri* to different doses of blackcurrant extract in the presence of lettuce in an olfactometer.

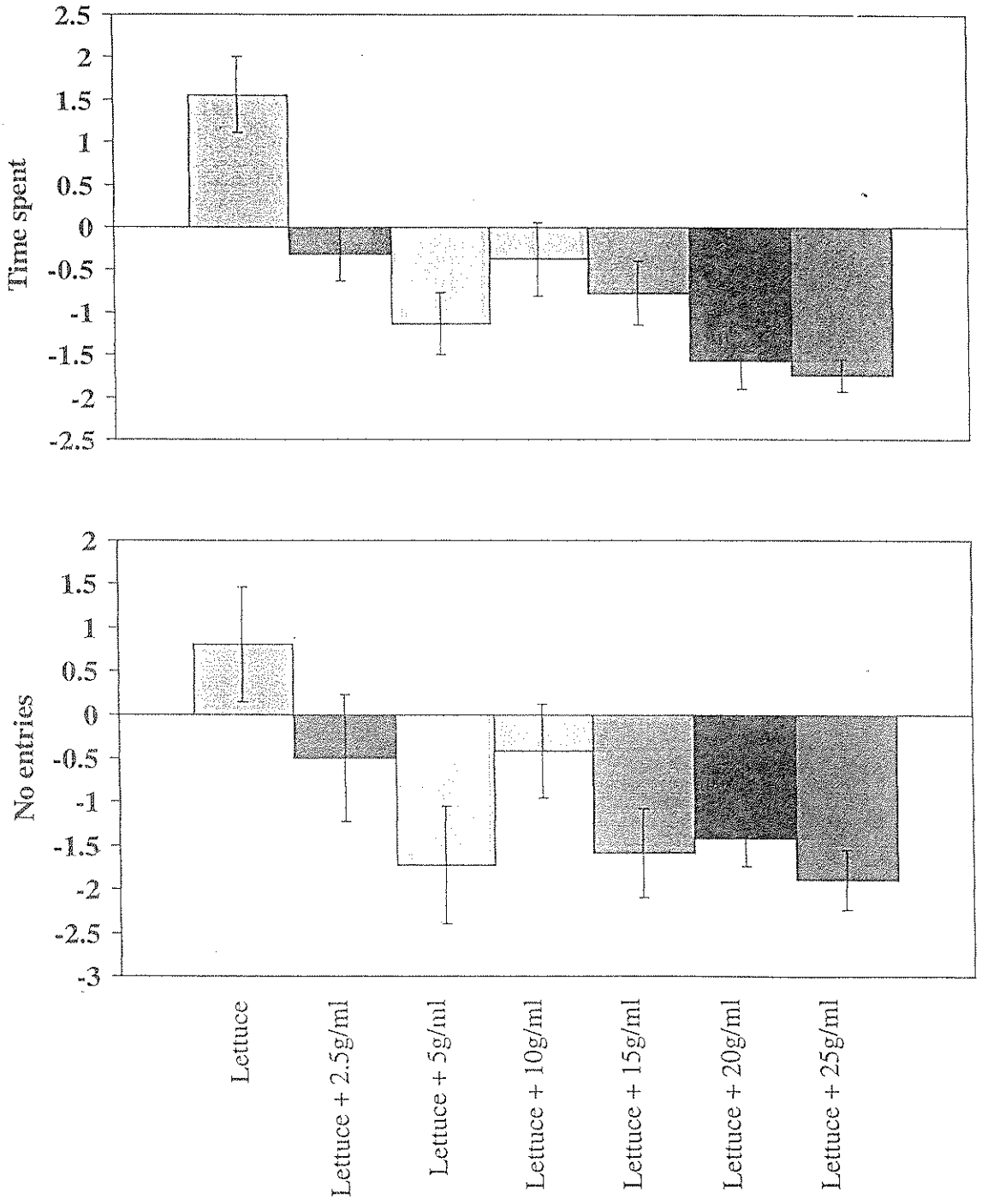


Figure 21 The behavioural response of alate *Nasonovia ribisnigri* to blackcurrant volatiles.

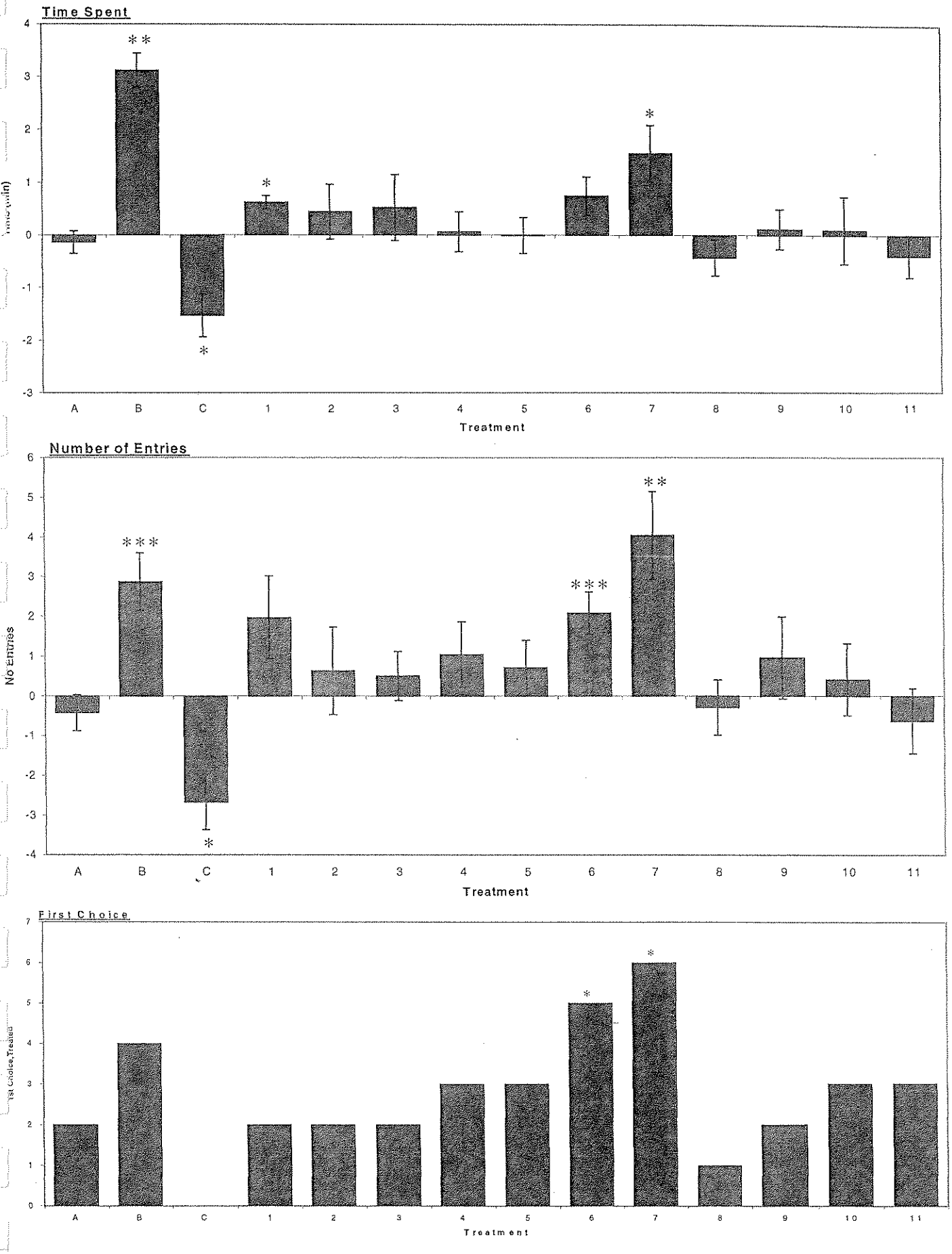


Figure 21 (cont.) Legend

Treatments

A) Blank Control

B) Lettuce Leaf 0.5g

C) Blackcurrant Extract 20 µl [25g/ml]

1) (E)-2-Hexenal

2) 5-Methyl furfural

3) 1-Octen-3-ol

4) Sabinene

5) β-Pinene

6) α-Terpinolene

7) Chrysanthenone

8) Methyl salicylate

9) Compound 'X'

10) β-Caryophyllene

11) (E)-β-Farnesene

Figure 22. Response of alate *Nasonovia ribisnigri* to lettuce with blackcurrant volatiles

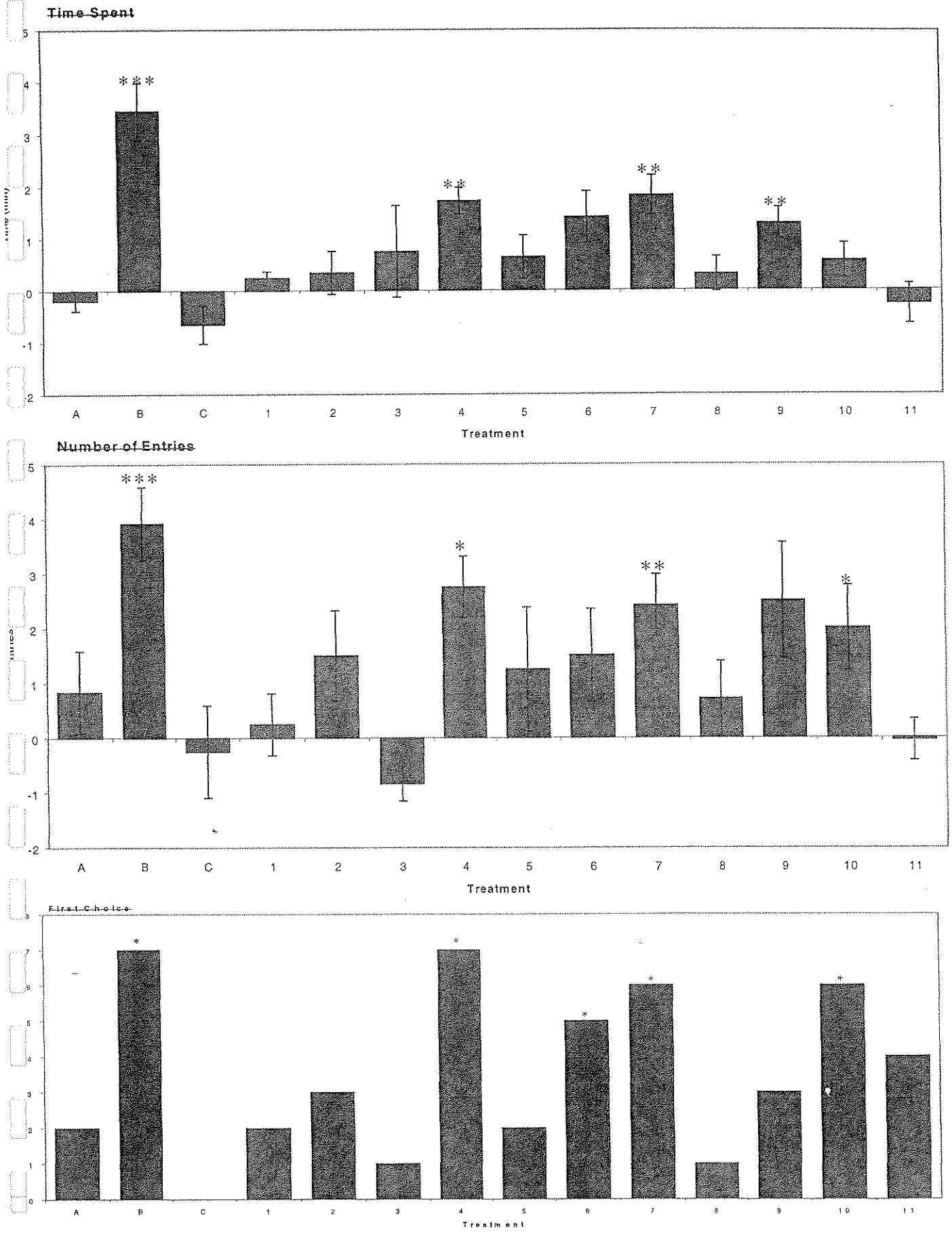


Figure 22 (cont.) Legend

Treatments

A) Blank Control

B) Lettuce Leaf 0.5g

C) Lettuce + Blackcurrant Extract 20 µl [25g/ml]

1) Lettuce + (E)-2-Hexenal

2) Lettuce + 5-Methyl furfural

3) Lettuce + 1-Octen-3-ol

4) Lettuce + Sabinene

5) Lettuce + β-Pinene

6) Lettuce + α-Terpinolene

7) Lettuce + Chrysanthenone

8) Lettuce + Methyl salicylate

9) Lettuce + Compound 'X'

10) Lettuce + β-Caryophyllene

11) Lettuce + (E)-β-Farnesene

Figure 23. Response of alate *Nasonovia ribisnigri* to a synthetic mixture of blackcurrant volatiles

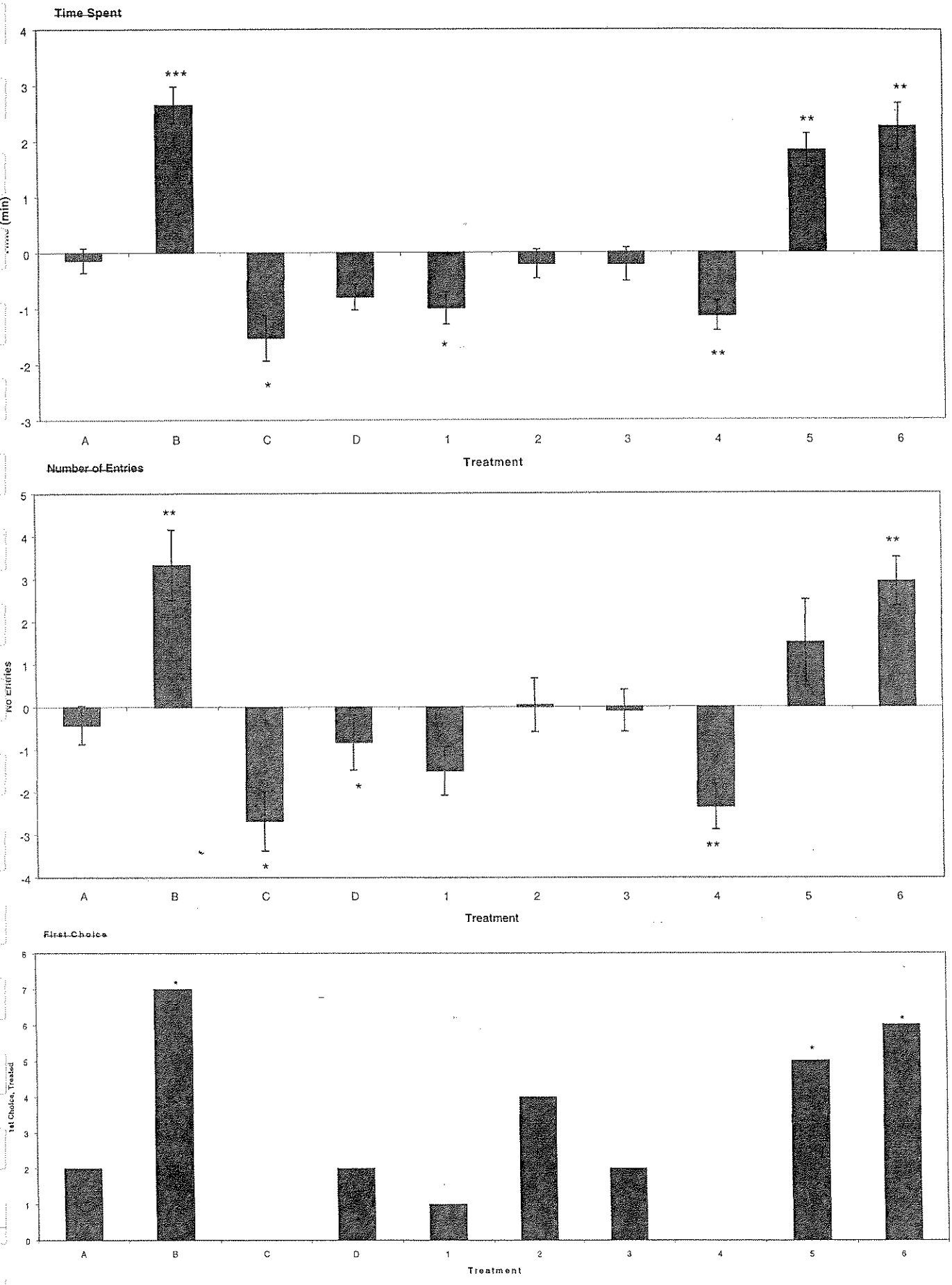


Figure 23. (cont.) Legend

Treatments

A) Blank Control

B) Lettuce Leaf 0.5g

C) Lettuce + Blackcurrant Extract 20µl [25g./ml]

D) Blackcurrant Extract 20µl [25g./ml]

1) Synthetic Mix 20µl [1mg/ml]

2) Synthetic Mix 20µl [0.1mg/ml]

3) Synthetic Mix 20µl [0.01mg/ml]

4) Lettuce + Synthetic Mix 20µl [1mg/ml]

5) Lettuce + Synthetic Mix 20µl [0.1mg/ml]

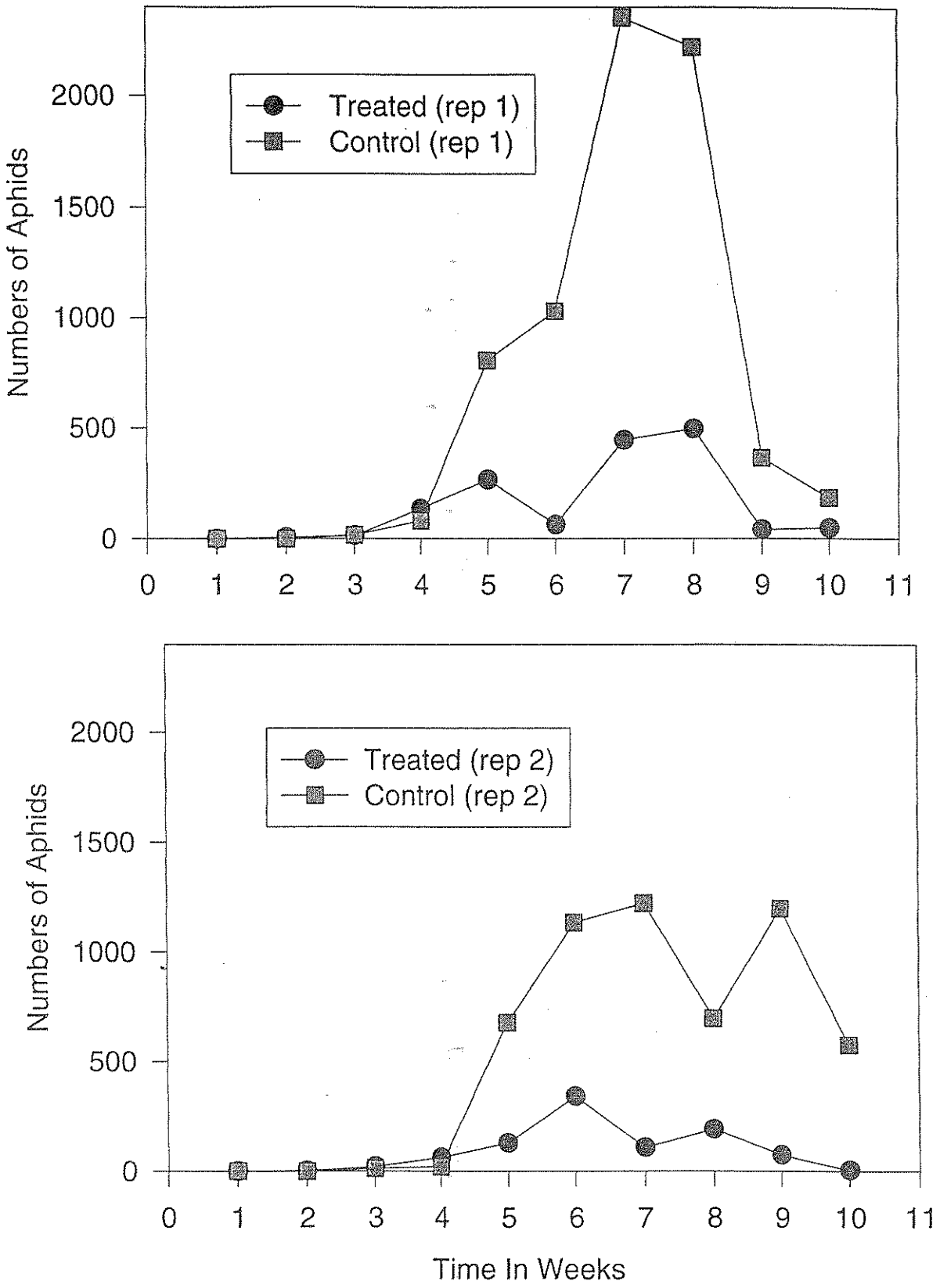
6) Lettuce + Synthetic Mix 20µl [0.01mg/ml]

NB. Synthetic mixture composed of the following compounds :

a) (E)-2-Hexenal
b) 5-Methyl furfural
c) 1-Octen-3-ol
d) Sabinene
e) β-Pinene
f) α-Terpinolene
g) Chrysanthenone
h) Methyl salicylate
i) Compound 'X'
j) β-Caryophyllene
k) (E)-β-Farnesene

with each compound in the mixture at a concentration of 1mg/ml, 0.1mg/ml or 0.01mg/ml respectively.

Figure 24 The effect of *Metarhizium anisopliae* on the numbers of *Pemphigus barsarius*.



Fungal conidia were incorporated into plant modules (25 ml) at 10^8 ml^{-1}. Figures represent the numbers of aphids counted on four plants sampled from each treatment on each occasion (2 reps, randomised plots, 16 plants per plot, commercial bed system)