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THE STATUS AND POTENTIAL OF PARASITOIDS OF SEED WEEVIL AND POD MIDGE ON WINTER OILSEED RAPE

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THE STATUS AND POTENTIAL OF PARASITOIDS OF SEED WEEVIL AND POD MIDGE ON WINTER OILSEED RAPE

by

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SUMMARY

Three parasitoid species were found to attack cabbage seed weevil (*Ceutorhynchus assimilis*), namely: *Trichomalus perfectus* and *Mesopolobus morys* (Hymenoptera: Pteromalidae), both ectoparasitoids of the larvae, and *Microtonus* sp. (Hymenoptera: Braconidae), an endoparasitoid of the adults. *T. perfectus* was the most important parasitoid, killing up to 71% of larvae inside pods in experimental field crops not sprayed with insecticide. *T. perfectus* was also widely distributed on unsprayed commercial crops in England & Wales, although levels of parasitism were usually lower. Adult females of *T. perfectus* exerted additional mortality on seed weevil larvae by host-feeding.

Five species of endoparasitoid were reared from cocoons of brassica pod midge (*Dasineura brassicae*), namely: ? *Aphanogmus abdominalis* (Hymenoptera: Ceraphonidae), *Omphale clypealis* (Hymenoptera: Eulophidae), *Inostemma* sp. and two species of *Platygaster* (A & B) (Hymenoptera: Platygastridae). *Platygaster* (species A) was the most abundant parasitoid of pod midge in winter rape, whereas *O. clypealis* was the predominant parasitoid of pod midge on spring rape. The multivoltine life-cycle and extended diapause strategy of pod midge presents problems for the assessment of the impact of parasitoids for their control, as do complex host/parasitoid interactions.

Platygaster (species A) was attracted to the chemical 2-phenylethyl isothiocyanate, a volatile substance released when brassicaceous plants are damaged. A novel, convenient trap, using isothiocyanates as lures, was developed to monitor parasitoids and midges.

The distribution of pests and parasitoids throughout the crop was never uniform, and no correlation was found between the spatial distributions of seed weevil and pod midge. When *T. perfectus* were searching for hosts within an oilseed rape crop, their distribution was negatively correlated with that of adult weevils. The in-field

distribution of *Platygaster* (species A), however, was positively correlated with that of pod midge.

A post-flowering spray of triazophos was harmful to *T. perfectus*, significantly reducing levels of parasitism in field-based experiments. A pyrethroid applied during flowering was less harmful to *T. perfectus* because it was applied before adults of this species had entered the crop. The effects of pyrethroid sprays on other parasitoids are unknown. The commercial use of triazophos has declined significantly since 1992 and numbers of the parasitoid *T. perfectus* on crops have increased over this period.

Farmers should encourage parasitoids on rape crops by resorting to using insecticides only where treatment thresholds for seed weevil are exceeded. When spraying is justified, a pyrethroid as recommended during flowering and not triazophos at the end of flowering should be used, to safeguard *T. perfectus*. The adoption of new treatment thresholds in 1992 means that now, even fewer commercial rape crops in England & Wales require treatment against seed weevil or pod midge; however, pesticide usage data confirm that many crops are still sprayed unnecessarily. Where treatment with an insecticide is justified, because seed weevil numbers exceed the threshold of 2 weevils per plant, crops usually exceed this thresholds by only a small margin. There is, therefore, considerable potential for naturally occurring parasitoids to exert sufficient control in such cases to obviate the need for applying a chemical treatment. This would tip the balance in favour of lower pesticide usage, and bring about both economic and environmental benefits.

KEY FINDINGS

1. Both cabbage seed weevil (*Ceutorhynchus assimilis*) and brassica pod midge (*Dasineura brassicae*) were attacked by various hymenopterous parasitoids.

2. The pteromalid *Trichomalus perfectus* was the most important and abundant parasitoid of seed weevil.

3. Adult females of *T. perfectus* caused additional pest mortality by feeding directly on weevil larvae (host-feeding).

4. *T. perfectus* was recorded in all rape-growing areas within England & Wales, offering potential for its future exploitation.

5. A species of *Platygaster* (family Platygastridae) was the most abundant parasitoid of pod midge in winter rape, whereas the eulophid *Omphale clypealis* was the predominant parasitoid of pod midge on spring rape.

6. Adults of *Platygaster* were attracted to the chemical 2-phenylethyl isothiocyanate, a volatile substance released when brassicaceous plants are damaged.

7. The insecticide triazophos, applied at the end of flowering, had a very detrimental effect on *T. perfectus* and was probably responsible for the general decline of this parasitoid on commercial crops.

8. A pyrethroid applied during flowering was less harmful to *T. perfectus*, because it was applied before the parasitoids had entered the crop, but the effects of such insecticides on other parasitoids are unknown.

9. Since 1992, the commercial use of triazophos has declined on oilseed rape and there is an indication that populations of *T. perfectus* might now be recovering.

10. Using insecticides against seed weevil can be counter-productive, by disrupting natural control exerted by *T. perfectus*.

11. The generally low levels of pest incidence, coupled with the confirmed presence of naturally occurring parasitoids, suggest that savings in inputs are possible and indicate that farmers should use insecticides only when absolutely necessary.

12. As crops rarely exceed treatment thresholds for seed weevil, or do so by only a small margin, in most cases farmers can choose with confidence the 'no spray' option and, thus, rely on *T. perfectus* to provide the necessary level of control.

RECOMMENDATIONS

1. Insect parasitoids on oilseed rape crops should be safeguarded, to enhance their beneficial role in controlling pests such as seed weevil and pod midge.

2. Farmers should adopt a more enlightened approach to pest control on oilseed rape, and should spray crops with insecticide only when pest numbers exceed economic treatment thresholds.

3. To safeguard parasitoids, triazophos should never be used on oilseed rape.

4. Practitioners (e.g. crop consultants) should be more pro-active in promoting the beneficial role that parasitoids play in controlling pests of oilseed rape and should use the findings of this research to advise farmers against the injudicious use of insecticides.

5. HGCA and MAFF should promote the benefits to farmers of a more enlightened approach to pest control on oilseed rape, with the aim of enhancing the potential benefits of parasitoids of seed weevil and pod midge; publication of information is suggested.

6. Results from this study should be incorporated into the Oilseed Rape Decision Support System currently being developed with MAFF funding.

7. Monitoring of pests, parasitoids and pesticide usage should continue to be funded, to measure the success of the recommended low-input strategy and any future changes.

8. Development of a cost-effective assessment method for pests and their parasitoids, that avoids the need for crop walking (possibly using traps baited with semiochemicals), is urgently needed, to speed uptake of the recommended low-input pest management strategy.

9. Research should be commissioned on the status and potential of parasitoids of pollen beetle on winter and spring rape, to provide information that would underpin the wider exploitation of parasitoids of spring/summer pests on these crops.

10. Studies of the parasitoids of seed weevil and pod midge on spring rape, including the effects of insecticides, should also be initiated, especially as the life-cycles of both pests and parasitoids (and pest/parasitoid interactions) are affected when both spring and winter rape are grown in the same area.

11. Insect taxonomy should be recognised as an important aspect of applied entomology and steps should be taken to address the current gaps in taxonomic expertise on parasitoids of potential benefit to farmers.

GLOSSARY

Braconid:	a member of the hymenopterous family Braconidae.
Cecidomyiid:	a member of the midge family Cecidomyiidae.
Crucifer:	any member of the flower family Brassicaceae (formerly known as the family Cruciferae)
Cultivar:	a plant variety produced by breeding rather than naturally occurring.
Delta trap:	a type of sticky insect trap, shaped like a small ridge tent, often baited with a synthetic pheromone.
Diapause:	a state of dormancy that occurs in the growth and development of an insect.
Ectoparasitoid:	a parasitoid that feeds externally on its host.
Endoparasitoid:	a parasitoid that feeds internally within its host.
Eulophid:	a member of the hymenopterous family Eulophidae.
Frass:	faecal matter and plant debris produced by insect feeding.
Glucosinolates:	sulphurous compounds found predominantly in plants of the family Brassicaceae (formerly known as the family Cruciferae).
Hymenopterous:	pertaining to the insect order Hymenoptera.
Inflorescence:	a flower head.

Interpolate:	to estimate, using mathematical techniques, the value of a function between the values already known.
Isothiocyanates:	toxic volatile compounds derived from the enzymatic breakdown of glucosinolates (q.v.) when plants are damaged.
Multivoltine:	having several generations per year (cf. univoltine).
Mymarid:	a member of the hymenopterous family Mymaridae.
Oviposition:	the act of using the ovipositor (q.v.) to deposit an egg.
Ovipositor:	the specialized egg-laying organ which, in most insects, is formed from outgrowths of the eighth and ninth abdominal segments.
Parasite:	an organism that lives at the expense of another, known as its host.
Parasitoid:	an organism in which the 'mother' is free-living but the immature stage develops as a parasite (q.v.), often killing its host.
Phenology:	the study of the effect of factors such as climate and weather conditions on the development of an organism.
Pheromone:	a chemical emitted by one organism that produces a predetermined behavioural response in a receiving individual of the same species.
Platygastrid:	a member of the hymenopterous family Platygasteridae

Pod midge:	a convenient term for brassica pod midge (*Dasineura brassicae*).
Pteromalid:	a member of the hymenopterous family Pteromalidae
Raceme:	a kind of inflorescence (q.v.), formed from a series of closely set stalked flowers arising from a common stem, as found in oilseed rape and many other plants.
Seed weevil:	a convenient term for cabbage seed weevil (*Ceutorhynchus assimilis*).
Semiochemical:	a generic term to embrace pheromones, plant volatiles and other behaviour-modifying chemicals transmitted between organisms.
Spring rape:	a convenient term for rape drilled in the spring and harvested in the same year (cf. winter rape).
Univoltine:	having only one generation per year (cf. multivoltine).
Winter rape:	a convenient term for rape drilled in the autumn and harvested in the following summer (and, hence, present throughout the winter) (cf. spring rape).

1. GENERAL INTRODUCTION

In spring/summer, winter rape crops in the UK are attacked by various pests, of which the cabbage seed weevil, *Ceutorhynchus assimilis* (Paykull) (Coleoptera: family Curculionidae) [commonly known as 'seed weevil'], and the brassica pod midge, *Dasineura brassicae* (Winnertz) (Diptera: family Cecidomyiidae) [commonly known as 'pod midge'], are most important (see Alford *et al.*, 1991).

Economic thresholds, based on counts of adult weevils that have migrated into crops, are available to guide farmers on the need or otherwise to apply insecticides against seed weevil, and these are updated as necessary to take account of changes in economic circumstances (see Lane & Walters, 1994). There are no specific thresholds for pod midge but control of this pest relies on the use of insecticides targetted against seed weevil, since it is damage caused by such weevils that allows the pod midge to lay its eggs in oilseed rape pods.

Evidence gathered over many years from national pest monitoring and pesticide usage surveys has shown that farmers often spray crops unnecessarily (i.e. when pest levels are below potentially damaging levels) and the amount of insecticide being applied annually is not justified on the basis of pest infestation levels (Alford *et al.*, 1991). Presumably, farmers spray either because they do not 'trust' thresholds or because they do not care to monitor for pests (which is a time-consuming exercise) and perceive that there is some benefit (or at least little or no disadvantage) in applying routine insecticide sprays, irrespective of pest levels.

In the mid-1970s, large numbers (often over 70 per cent) of seed weevil larvae on commercial crops of winter rape in England were killed by parasitoids (D. V. Alford, *in litt.*), most of which were believed to be ectoparasitic larvae of the parasitoid *Trichomalus perfectus* (Walker) (Hymenoptera: family Pteromalidae). This species is a recognised natural enemy of seed weevil in mainland Europe where, again, high levels of parasitism have been reported (von Rosen, 1964; Laborius, 1972; Dmoch, 1975; Lerin, 1987). By the late 1980s and early 1990s, however, parasitoids were rarely found on commercial crops in England; it was thought possible that the apparent decline in parasitoids was due to the widespread use of broad-spectrum insecticides which occurred on winter oilseed rape throughout the late 1970s and 1980s. Prior to this time, oilseed rape crops were far less often sprayed with pesticides.

The reasons for the decline in parasitoids and the status of species such as *T. perfectus* was believed to require urgent investigation, especially as there appeared to be a potential opportunity to exploit such parasitoids to the benefit of farmers and to counter the clear imbalance between current pesticide usage and the likely pest risk on winter rape crops.

In 1992, a three-year project commenced with the following objectives:

a) to determine the present status of insect parasitoids of seed weevil and pod midge on winter oilseed rape;

b) to investigate the effect of pesticides applied during and after flowering on parasitoids of these two pests;

c) to investigate possible strategies for farmers to exploit parasitoid populations in the control of seed weevil and pod midge.

This work was subdivided into three specific but inter-related areas:

a) multi-site field experiments, with the main aim of identifying the effect of insecticides on field populations of parasitoids, such as *T. perfectus*, and levels of observable parasitism of seed weevil and pod midge;

b) biological and phenological studies on seed weevil and pod midge, and their parasitoids;

c) analysis of data from ADAS/CSL Pest Monitoring studies to provide a broader perspective on pest incidence and levels of parasitism.

To supplement the data obtained and observations made during these studies an extensive worldwide literature search relating to parasitoids of seed weevil and pod midge was made. Presentation of details of the various papers obtained is is beyond the scope of the current report but the information is available in Murchie (1995).

2. MULTI-SITE FIELD EXPERIMENTS

To obtain information on the status of parasitoids of seed weevil and pod midge, and possible effects of insecticides upon them, experiments were done at various sites from 1992 to 1994. On some experimental plots, the insecticide triazophos (Hostathion) was used as a post-flowering treatment (mirroring commercial practice). On others, the pyrethroid alphacypermethrin was applied as a flowering treatment (again mirroring commercial practice). Reference to growth stage (GS) in this report (e.g. to identify treatment or assessment times) follow the notation of Sylvester-Bradley & Makepeace (1984). Alphacypermethrin was selected as a representative of the various other commercially available pyrethroids recommended for use against seed weevil on oilseed rape crops (see, for example, Whitehead, 1995). In each year, slight differences in experimentation were made, as detailed below.

2.1 Year 1 (1992 experiment)

2.1.1 *Introduction*

In 1992, a multi-site field experiment was initiated at three sites: ADAS Boxworth, Cambridgeshire; ADAS High Mowthorpe, Yorkshire; IACR Rothamsted: Woburn Farm, Bedfordshire. At each site an area of winter oilseed rape adjacent to a headland was selected. The chosen crop area was divided into 3 plots (each 48 × 48 m), separated by gaps of 48 m at ADAS Boxworth and IACR Woburn. At ADAS High Mowthorpe, where less crop was available, the gaps between plots were 12 m. It was decided to keep individual site plots large and unreplicated during the first year, to establish gross differences between treatments and to allow for insect movement.

2.1.2 *Insecticide treatments*

Insecticide treatments were as follows:

a) Untreated

b) Alphacypermethrin (as Fastac) at 200 ml/ha, applied in 200 litres of water/ha at 20% pod set stage (GS 4.8).

c) Triazophos (as Hostathion) at 1 litre/ha, applied in 200 litres of water/ha at the end of flowering when the crop had an overall green appearance (GS 6.1).

Treatment dates were as follows:

Site	*Treatment*	*Date of application*
ADAS Boxworth	Alphacypermethrin	28 May 1992
ADAS High Mowthorpe	Alphacypermethrin	1 June 1992
IACR Woburn	Alphacypermethrin	3 June 1992
ADAS Boxworth	Triazophos	12 June 1992
ADAS High Mowthorpe	Triazophos	23 June 1992
IACR Woburn	Triazophos	9 June 1992

2.1.3 *Monitoring of adult seed weevils*

At each site, adult seed weevils were monitored in each of the three plots.

At weekly intervals from the green-bud stage (GS 3.3) until one week after the date of the triazophos treatment, 20 plants per plot were beaten onto a white tray and the number of adult weevils present recorded.

Beating points were spaced evenly (2.5 m apart) along a central transect from the headland edge to within a few metres of the far (inner) edge of each plot.

2.1.4 *Monitoring of adult parasitoids*

At IACR Woburn, water traps were used to monitor adult parasitoids (primarily females of the pteromalid *Trichomalus perfectus*, a known ectoparasitoid of seed weevil larvae). Seed weevil adults caught in these traps were also counted weekly.

2.1.5 *Assessment of plant pest infestation levels*

At each site, two weeks after the end of flowering, 20 plants were removed from each plot along the beating transect line and the following were determined:

a) The number of secondary racemes per plant;

b) The number of pods on each main and the third lowest secondary raceme per plant (including both damaged and undamaged pods);

c) The number of split (midge-damaged) pods on each main and third lowest secondary raceme.

In addition, 20 pods per plant (10 from the main raceme and 10 from the third lowest secondary raceme) were examined and the following determined:

a) The number of pods with a seed weevil exit hole;

b) The number of pods with seed weevil eggs, live, parasitised or dead seed weevil larvae;

c) The number of pods with pod midge eggs, live or parasitised pod midge larvae.

At ADAS High Mowthorpe, plant infestation assessments were repeated two weeks later on 10 plants per plot, as it was thought that the first assessment may have been done before the main pod midge attack had occurred (but see discussion, below).

2.1.6 *Results*

Seed weevil adults migrated into the crops during the latter half of April and early May, numbers declining from mid-June onwards. Pest numbers reached potentially significant levels, if applying a treatment threshold of '1 weevil per plant' rather than the '2 weevils per plant' threshold introduced from 1992 (see **Section 4.3.1**), only at ADAS High Mowthorpe, where they reached a maximum (an average of 1.5 weevils per plant) in mid-May.

Numbers of adult weevils at the other two sites were low. Differences in adult numbers were subsequently reflected in the pod assessments and infestation levels (including weevil exit holes) (**Table 2.1**).

Table 2.1 *Extent of seed weevil infestation, 1992.*

Site	*Infestation level*
ADAS Boxworth	2.4 per cent
ADAS High Mowthorpe	27.3 per cent (first examination) 19.7 per cent (second assessment)
IACR Woburn	4.9 per cent

Seed weevil larval infestation levels varied according to treatment (**Table 2.2**).

In many instances, high levels of parasitism were recorded, most thought to be due to *Trichomalus perfectus* (**Table 2.3**). At all sites, levels of pod midge attack were low (**Table 2.4**).

Table 2.2 *Effect of insecticide treatment on seed weevil larval infestations, 1992.*

Site	*Treatment*	*Relative infestation*
ADAS Boxworth	Untreated	66 per cent
	Alphacypermethrin	17 per cent
	Triazophos	17 per cent
ADAS High Mowthorpe	Untreated	36 per cent
	Alphacypermethrin	22 per cent
	Triazophos	42 per cent
IACR Woburn	Untreated	44 per cent
	Alphacypermethrin	29 per cent
	Triazophos	27 per cent

Table 2.3 *Extent of parasitism of seed weevil larvae by* T. perfectus, *1992.*

Site	*Treatment*	*Level of parasitism*
ADAS Boxworth	Untreated	21 per cent
	Alphacypermethrin	60 per cent
	Triazophos	0 per cent
ADAS High Mowthorpe	Untreated	54 per cent
	Alphacypermethrin	22 per cent
	Triazophos	20 per cent
IACR Woburn	Untreated	73 per cent
	Alphacypermethrin	76 per cent
	Triazophos	37 per cent

Table 2.4 *Extent of pod midge infestation, 1992.*

Site	*Infestation level*
ADAS Boxworth	0.4 per cent
ADAS High Mowthorpe	2.5 per cent (first examination)
	2.2 per cent (second assessment)
IACR Woburn	0.9 per cent

2.1.7 *Discussion*

As the multi-site experiment was preliminary, with unreplicated plots, no statistical analyses of data were appropriate. The results do, however, provide useful pointers for more detailed experimentation in year 2 (see **Section 2.2**).

The high levels of seed weevil parasitism, especially in untreated plots, were encouraging; levels in some alphacypermethrin-treated plots also seemed usefully high. At ADAS High Mowthorpe, the plots treated with alphacypermethrin had the lowest infestations of seed weevil larvae, suggesting that this insecticide may have killed many weevil adult females before they had oviposited.

At all sites the application of triazophos reduced the numbers of ectoparasitic larvae. Further, if the number of weevil exit holes is taken as an index of successful emergence of weevil larvae then the application of triazophos was counter-productive to pest control, because more weevil larvae emerged.

No ectoparasitoids of pod midge were found.

2.2 Year 2 (1993 experiment)

2.2.1 *Introduction*

As in 1992, the multi-site field experiment was located on three sites: ADAS Boxworth, ADAS High Mowthorpe and IACR Rothamsted Experimental Farm, Hertfordshire, not Woburn Farm, Bedfordshire). The main aim was to produce further information on the effect of insecticides on *Trichomalus perfectus* and additional data on the status of parasitoids.

In 1993, plots at all three sites were replicated (they were unreplicated in the 1992 experiment). Also, an additional insecticide treatment (alphacypermethrin applied on the same date as triazophos) was included as an experimental 'tool' to allow a direct comparison between insecticides and help clarify the effects of the post-flowering triazophos application. Unlike triazophos, which kills adult insects and also weevil larvae within pods, alphacypermethrin (if applied at the end of flowering) would affect only adult parasitoids, assuming adult weevils were no longer active in the crop or of no consequence at that time (see **Fig. 2.1**).

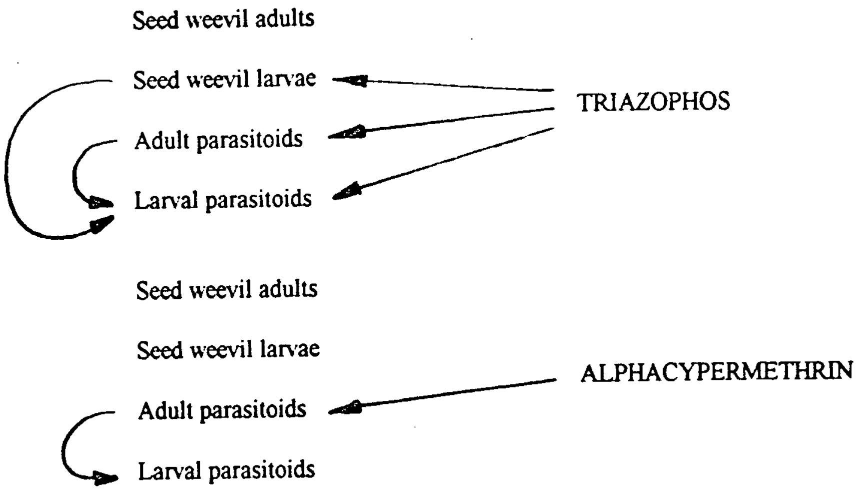

Fig. 2.1 Comparison of direct (straight arrows) and indirect (curved arrows) effects of alphacypermethrin and triazophos on seed weevil and parasitoids (*T. perfectus*).

2.2.2 *Treatments*

Treatments were applied as follows:

a) Untreated.

b) Alphacypermethrin (as Fastac) at 200 ml/ha, applied in 200 litres of water/ha at 20% pod set stage (GS 4.8).

c) Alphacypermethrin (as Fastac) at 200 ml/ha, applied in 200 litres of water/ha at the end of flowering when the crop had an overall green appearance (GS 6.1).

d) Triazophos (as Hostathion) at 1 litre/ha, applied in 200 litres of water/ha at the end of flowering when the crop had an overall green appearance (GS 6.1).

Treatment dates were as follows:

Site	*Treatment*	*Date of application*
ADAS Boxworth	Alphacypermethrin (flowering)*	18 May 1993
ADAS High Mowthorpe	Alphacypermethrin (flowering)*	28 May 1993
IACR Rothamsted	Alphacypermethrin (flowering)*	28 May 1993
ADAS Boxworth	Alphacypermethrin (post-flowering)**	4 June 1993
ADAS High Mowthorpe	Alphacypermethrin (post-flowering)**	21 June 1993
IACR Rothamsted	Alphacypermethrin (post-flowering)**	22 June 1993
ADAS Boxworth	Triazophos (post-flowering)	4 June 1993
ADAS High Mowthorpe	Triazophos (post-flowering)	21 June 1993
IACR Rothamsted	Triazophos (post-flowering)	22 June 1993

* For convenience in the text: alphacypermethrin 'normal'.

** For convenience in the text: alphacypermethrin 'late'.

2.2.3 *Design*

ADAS Boxworth: six replicates of the four treatments, plots 24 × 24 m separated by 4 m discards; treatments allocated at random. *ADAS High Mowthorpe*: six replicates of the four treatments, plots 24 × 24 m separated by 6 m discards; treatments allocated at random. *IACR Rothamsted*: six replicates of the four treatments, plots 20 × 20 m separated by 4 m discard areas; treatments allocated at random.

2.2.4 *Assessment methods*

Similar methods to 1992 were used to monitor adult seed weevils, adult parasitoids and to assess pest and parasitoid levels within pods, but mechanical monitoring for adults was discontinued and replaced by more intensive water trapping. The water traps (emptied weekly) were operated at ADAS Boxworth from 14 April to the end of June, at ADAS High Mowthorpe from 15 April to mid-July and at IACR Rothamsted from 14 April to late July. At each site, one trap was located in each of the four treatments in one of the replicated blocks.

2.2.5 *Monitoring of seed weevils – results*

At ADAS Boxworth adult seed weevils were recorded throughout the trapping period, peak numbers being reached in early June (**Table 2.5**). Numbers recorded, however, were low throughout the experiment.

Table 2.5 *Numbers of adult seed weevils caught in water traps at ADAS Boxworth, 1993.*

Date traps emptied	*Crop growth stage (GS)*	*Untreated*	*Alphacypermethrin*		*Triazophos*
			'Normal'	*'Late'*	
21 April	4.1	1	0	0	0
28	4.5	0	0	0	0
5 May	4.8	0	2	0	1
12	5.2	1	0	0	3
19	5.7	2	–	2	3
26	5.9	1	1	0	0
2 June	6.1	2	12	24	7
9	6.2	5	2	16	1
16	6.3	0	0	0	0
23	6.4	0	1	0	0
30	6.5	0	1	3	1
7 July	6.6	0	1	3	0

At ADAS High Mowthorpe, seed weevils were caught from late April to mid-July, with peak numbers being recorded in early May, at GS 4.1 (10% flower buds open) (**Table 2.6**).

Table 2.6 *Numbers of adult seed weevils caught in water traps at ADAS High Mowthorpe, 1993.*

Date traps emptied	*Crop growth stage (GS)*	*Untreated*	*Alphacypermethrin 'Normal'*	*Alphacypermethrin 'Late'*	*Triazophos*
21 April	3.1	0	0	0	0
28	3.7	3	0	0	1
5 May	4.1	140	42	63	70
12	4.4	9	1	7	4
19	4.6	6	6	21	3
26	4.8	6	12	49	11
2 June	4.8	4	2	0	16
9	5.2	23	7	31	17
16	5.3	6	2	9	6
23	5.5	4	5	3	3
30	5.8	6	4	0	3
7 July	5.8	6	1	1	7
14	–	2	1	0	2

At Rothamsted, seed weevils were recorded from late April to mid-July, with greatest numbers being found in early to mid-May (**Fig. 2.2**).

2.2.6 *Monitoring of* Trichomalus perfectus – *results*

At ADAS Boxworth, a small number of adult females of *T. perfectus* were found in the water traps, most during early to mid-June (**Table 2.7**). Small numbers were also found at ADAS High Mowthorpe (**Table 2.8**).

At Rothamsted, the first female *T. perfectus* was recorded on 12 May; numbers remaining low with a maximum of 4 caught in one trap on 16 June.

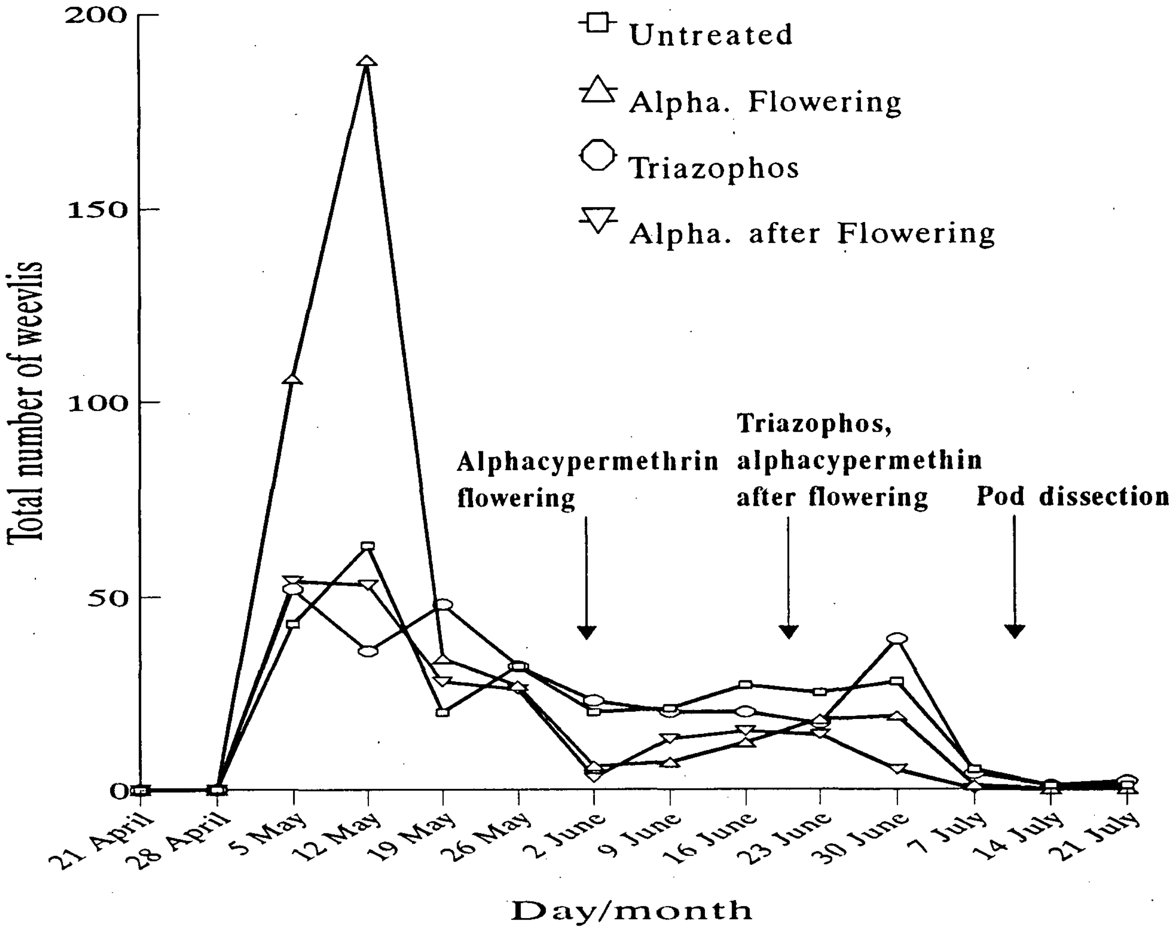

Fig. 2.2 Phenology of seed weevil on winter rape – data dervied from yellow-bowl water trap catches at IACR Rothamsted (1993).

Table 2.7 *Numbers of adult female* T. perfectus *caught in water traps at ADAS Boxworth, 1993.*

Date traps emptied	*Untreated*	*Alphacypermethrin* *'normal'*	*'late'*	*Triazophos*
21 April	0	0	1	0
28	1	1	0	0
5 May	0	0	0	1
12	0	0	0	1
19	0	–	0	0
26	0	0	2	0
2 June	1	0	0	1
9	1	1	0	2
16	4	0	4	2
23	1	0	0	0
30	2	1	0	0
7 July	0	0	0	1
Total:	10	3	7	8

Table 2.8 *Numbers of adult female* T. perfectus *caught in water traps at ADAS High Mowthorpe, 1993.*

Date traps emptied	*Untreated*	*Alphacypermethrin* *'normal'*	*'late'*	*Triazophos*
21 April	0	0	0	0
28	0	0	0	0
5 May	0	1	0	0
12	0	0	0	0
19	1	1	0	0
26	1	1	3	0
2 June	3	1	0	1
9	0	0	0	1
16	0	1	0	1
23	0	0	0	0
30	0	0	0	0
7 July	3	1	2	1
14	1	0	1	1
Total:	9	6	6	5

2.2.7 *Pod assessments – results*

At ADAS Boxworth, pest infestations in pods were very low (**Table 2.9**) and no seed weevil larval exit holes or parasitised seed weevil larvae were found.

Table 2.9 *Number of pods infested with seed weevil or pod midge larvae at ADAS Boxworth, 1993.*

	Seed weevil		*Pod midge*	
Raceme:	*primary*	*secondary*	*primary*	*secondary*
Untreated	0	3	2	1
Alphacypermethrin 'normal'	0	0	0	0
Alphacypermethrin 'late'	0	1	1	1
Triazophos	0	1	0	0

At ADAS High Mowthorpe, pod infestations by seed weevil and pod midge were also low (**Table 2.10**) but a small number of parasitised weevil larvae were found (**Table 2.11**). At IACR Rothamsted, seed weevil infestations were higher than at the two ADAS sites and parasitism very pronounced (**Table 2.12 & Fig. 2.3**). The incidence of parasitism differed between treatments ($P < 0.001$) as did the number of dead weevil larvae found.

Table 2.10 *Percentage of pods infested by seed weevil and/or pod midge at ADAS High Mowthorpe, 1993.*

	Seed weevil eggs or live larvae (dead larvae)		*Pod midge eggs or larvae*	
Raceme:	*primary*	*secondary*	*primary*	*secondary*
Untreated	1.7 (2.3)	2.3 (0.7)	3.7	4.3
Alphacypermethrin 'normal'	3.4 (2.3)	1.7 (0.3)	2.0	2.7
Alphacypermethrin 'late'	4.3 (3.7)	6.0 (3.0)	4.0	1.6
Triazophos	0.6 (5.0)	2.0 (2.3)	0.0	2.6

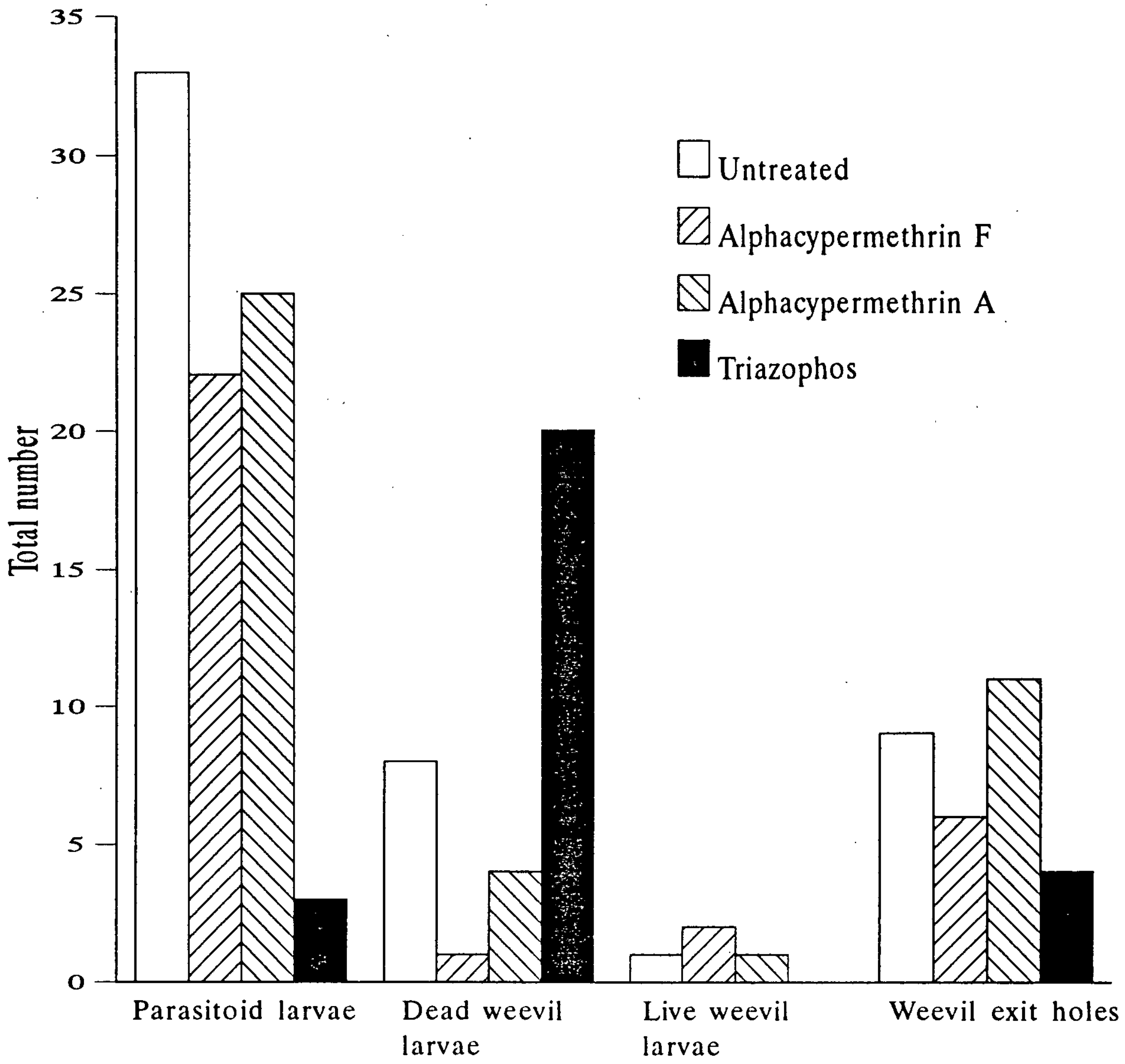

Fig. 2.3 Effects of insecticides on parasitoid and seed weevil infestations of pods at IACR Rothamsted (1993). F – appled at flowering; A – applied after flowering.

Table 2.11 *Incidence of parasitism of seed weevil larvae in pods at ADAS High Mowthorpe, 1993.*

	Pod on primary racemes (%)	*Pods on secondary racemes (%)*
Untreated	4.0	2.3
Alphacypermethrin 'normal'	0.3	0.3
Alphacypermethrin 'late'	4.3	1.3
Triazophos	0.7	1.3

($P < 0.01$). The number of live weevil larvae found was also low, but differences between treatments were not statistically significant ($P = 0.53$); nor were there statistically significant differences between treatments when numbers of weevil larval exit holes were compared ($P = 0.24$).

Table 2.12 *Incidence of infestation by seed weevil and the incidence of parasitism of seed weevil larvae in pods at IACR Rothamsted, 1993.*

	Seed weevil pod infestation (%)	*Parasitism of seed weevil larvae (%)*
Untreated	8.5	65
Alphacypermethrin 'normal'	5.2	71
Alphacypermethrin 'late'	6.8	61
Triazophos	4.5	11

2.2.8 *Discussion*

The low levels of pest attack in 1993 prevented analysis of data from ADAS Boxworth and ADAS High Mowthorpe, although data on parasitism at ADAS High Mowthorpe suggested that the post-flowering ('late') alphacypermethrin was not as directly damaging to adult parasitoids as the post-flowering application of triazophos. Data from Rothamsted, which indicate the same trend, were more meaningful. The purpose of the 'late' alphacypermethrin treatment was to compare the direct effect of this insecticide (i.e. whether it killed adults of *T. perfectus* parasitoids before they laid eggs) with that of triazophos. Clearly, the 'late' alphacypermethrin treatment was less 'damaging' than triazophos. The relatively high level of parasitism in 'late' alphacypermethrin-treated plots was either an indication of a) its toxicity, or b) its lack of persistence (i.e. it allowed successful re-invasion by egg-laying parasitoids); alternatively, egg-laying by parasitoids may have occurred before the insecticide was applied.

2.3 Year 3 (1994 experiment)

2.3.1 *Introduction*

In 1994, the intention of the multi-site work at ADAS Boxworth, ADAS High Mowthorpe and IACR Rothamsted was to seek confirmation of the earlier findings, with particular reference to the effects of a standard insecticide treatment (applied to control seed weevil) on the parasitoid *T. perfectus*.

2.3.2 Methods and treatments

These were as identified in 1993 (**Section 2.2**), except for the omission of the 'late' alphacypermethrin treatment and the inclusion at IACR Rothamsted 'bagged' plants within the untreated plots to exclude adult parasitoids soon after (on 11 June) the application of a post-flowering insecticide to triazophos-treated plots. Ten rape plants in each untreated plot were 'bagged' by enclosing racemes with pods in muslin bags (each 1.5 × 0.5 m), then securing the bags to the bottom of the plant's stem, using PVC tape. The bags remained in position for until 26 July when pods were collected for disssection.

Treatment dates were as follows:

Site	*Treatment*	*Date of application*
ADAS Boxworth	Alphacypermethrin (flowering)	27 May 1994

ADAS High Mowthorpe	Alphacypermethrin (flowering)	13 June 1994*
IACR Rothamsted	Alphacypermethrin (flowering)	1 June 1994
ADAS Boxworth	Triazophos (post-flowering)	30 June 1994
ADAS High Mowthorpe	Triazophos (post-flowering)	26 June 1994
IACR Rothamsted	Triazophos (post-flowering)	8 July 1994
IACR Rothamsted	Some untreated plants 'bagged'	11 July 1994

* Unavoidably, this treatment was delayed until 80% petal-fall because of unfavourable spraying conditions during most of the flowering period, including all of the critical mid-flowering stage.

2.3.2 *Results*

Data from the pod assessments at ADAS Boxworth showed very low levels of seed weevil or pod midge attack (**Table 2.13**), only 22 of the 1,800 pods examined being damaged by pests. Three of the seed weevil larvae found in pods from triazophos-treated plots were parasitised. However, because of the low numbers involved, statistical analysis was not possible and no conclusions could be drawn from the data.

Table 2.13 *Percentage of pods infested with seed weevil and pod midge and percentage of pods split (numbers in parentheses are number of pods) at ADAS Boxworth, 1994.*

	Seed weevil larvae		*Pod midge larvae*		*Split pods*	
Raceme:	*Primary*	*Secondary*	*Primary*	*Secondary*	*Primary*	*Secondary*
Alphacypermethrin	0.0 (0)	0.0 (0)	0.0.(0)	0.3 (1)	0.3 (1)	0.0 (0)
Triazophos	3.3 (10)	1.0 (3)	0.0 (0)	0.0 (0)	1.0 (3)	0.0 (0)
Untreated	1.3 (4)	0.7 (2)	0.3 (1)	0.3 (1)	0.3 (1)	0.0 (0)

Numbers of seed weevil, pod midge and *T. perfectus* recorded at ADAS High Mowthorpe in 1994, where weather conditions were generally poor, were also very low. Some seed weevil eggs were found in pods from untreated plots but none was found in pods from insecticide-treated plots. No pods examined contained live or dead seed weevil larvae, or evidence of parasitism, and only four pods in each treatment sample contained larvae of pod midge.

The very low larval infestation levels in pods reflected the low numbers of seed weevil adults found in the crop during crop monitoring; adult females of *T. perfectus* were also present in only small numbers (**Table 2.14**).

Table 2.14 *Weekly water trap catches at ADAS High Mowthorpe, 1994.*

Date trap emptied	*Seed weevil adults caught*	*Adult females of* T. perfectus *caught*
4 May	6	1
11 May	1	1
18 May	0	0
25 May	0	0
1 June	2	0
8 June	8	2
15 June	13	2
22 June	0	6
29 June	15	0
Total:	45	12

Data from the insecticide experiment at IACR Rothamsted show a similar pattern to those in 1993. Significant differences occurred between treatments (untreated, alphacypermethrin and triazophos) in the number of parasitoid larvae ($P < 0.05$) and the number of dead weevil larvae ($P < 0.05$) but not in the number of weevil exit holes ($P > 0.05$) (**Fig. 2.4**). The number of weevil-infested pods (9.75% in untreated; 6.63% in alphacypermethrin-treated plots; 7.87% in triazophos-treated plots), however, did not differ between treatments ($P > 0.05$).

As in previous years, a significantly lower level of parasitism by *T. perfectus* occurred in triazophos-treated plots ($P < 0.01$): 51.3% in untreated; 49.1% in

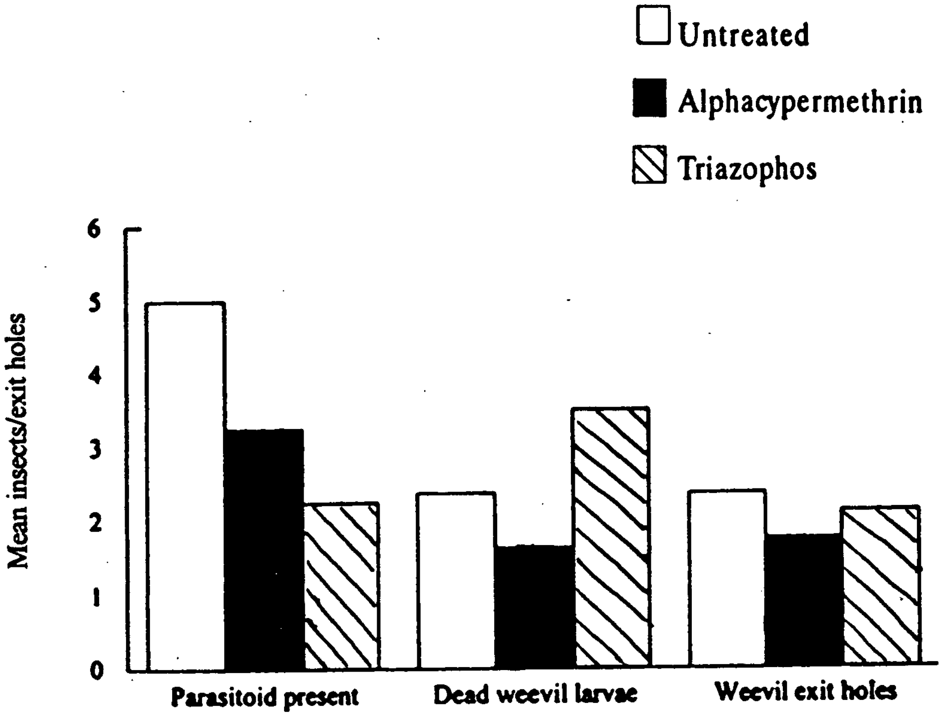

Fig. 2.4 Effects of insecticides on parasitoid and seed weevil infestations of pods at IACR Rothamsted (1994).

alphacypermethrin-treated plots; 28.6% in triazophos-treated plots. The level of seed weevil parasitism in 'bagged' plants was also 28.6%.

Pods from plants 'bagged' in untreated plots from about the time that the triazophos treatment was applied contained significantly fewer parasitoid larvae ($P < 0.05$) than those from 'unbagged' plants in untreated plots but significantly more weevil exit holes ($P < 0.05$). Numbers of dead weevil larvae, however (although lower in pods from 'bagged' plants), did not differ significantly ($P = 0.09$) (**Fig. 2.5**). The percentage weevil larval infestation in untreated, alphacypermethrin, triazophos and 'bagged' samples was 9.8, 6.6, 7.9 and 8.0, respectively.

2.3.3 *Discussion*

As in 1993, high levels of parasitism by *Trichomalus perfectus* were found in 1994 at the IACR Rothamsted site. The effects of the insecticide applications were also the same, with triazophos again proving particularly detrimental to parasitoids. Use of 'bagged' plants, to exclude parasitoids and, thus, mimic parasitoid mortality through insecticide application, suggested that triazophos was directly harmful, probably killing adult parasitoids searching for their hosts. Although differences were not statistically significant, the lower number of dead larvae in 'bagged' than in 'unbagged' plants suggested that adult females parasitoids were probably killing weevil larvae directly by host-feeding (see **Section 3.2.1**).

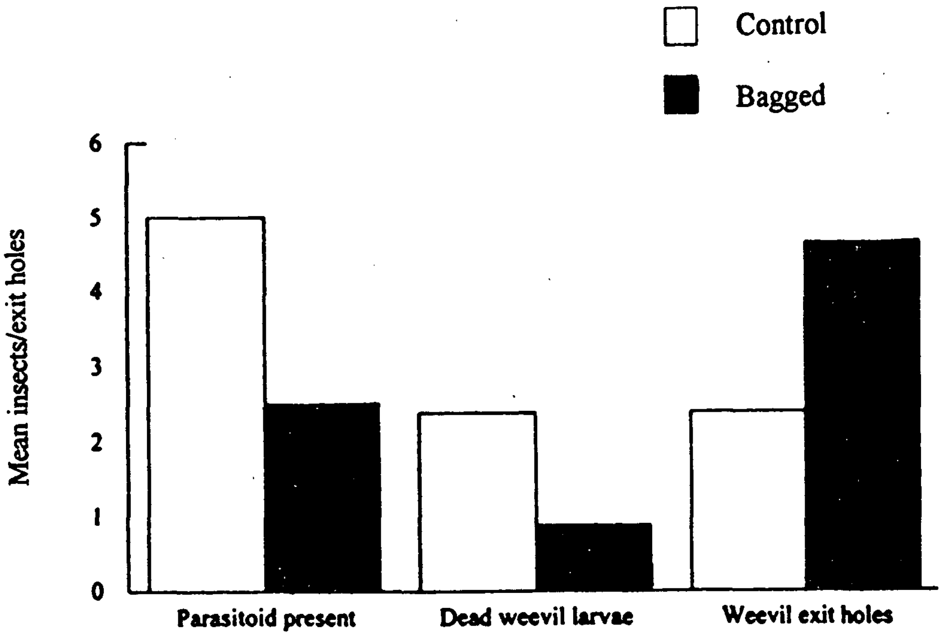

Fig. 2.5 Effects of excluding females of *T. perfectus* from unsprayed plants from about the time that a post-flowering insecticide treatment would be applied.

3. BIOLOGICAL STUDIES

3.1 Parasitoid species reared from seed weevil and pod midge

3.1.1 *Introduction*

There are no published UK data on the species composition of parasitoids attacking seed weevil or pod midge in oilseed rape. The most recent study (Nasreldin, 1973) dealt solely with parasitoids attacking seed weevil on spring-sown mustard.

Literature searches on parasitoids of seed weevil and pod midge show that in Europe over twenty species are cited as attacking each pest (Williams & Walton, 1990; Murchie, 1995). These parasitoids have varied life-strategies and attack different life-stages of their hosts. The aim of these studies was to determine the status of parasitoids attacking seed weevil and pod midge in oilseed rape, with particular reference to winter rape.

3.1.2 *Materials and methods*

Seed weevil. Ectoparasitoids of larvae were obtained by dissecting rape pods and examining all larvae found, using a binocular microscope; any parasitoid larvae discovered were reared to adulthood and identified. Endoparasitoids of adult weevils were obtained either by dissecting them from field-collected weevils or by rearing them from weevils kept in the laboratory.

Pod midge. Midge larvae and occupied midge cocoons were collected from the field and, in order to rear-out adults, placed in moist sand within glass vials kept at 18°C. Any adult parasitoids that appeared were collected on emergence and identified.

3.1.3 *Results*

Seed weevil. Three parasitoid species were found attacking seed weevil: *Trichomalus* *perfectus* (Walker) and *Mesopolobus morys* (Thomson), both ectoparasitoids of larvae inside pods, and *Microtonus* sp., an endoparasitoid of adult weevils (**Table 3.1**). No egg parasitoids or endoparasitoids of weevil larvae were found.

T. perfectus was the most abundant parasitoid, with 97% of ectoparasitoids reared being of this species. *Mesopolobus morys* and *Microtonus* sp. occurred only in low numbers.

Table 3.1 *Hymenopterous parasitoids of seed weevil and pod midge reared at IACR Rothamsted, 1992–1995.*

Host	*Stage*	*Parasitoid species*	*Family*	*Strategy*
Seed weevil	Larva	*Trichomalus perfectus*	Pteromalidae	Ectoparasitoid
	Larva	*Mesopolobus morys*	Pteromalidae	Ectoparasitoid
	Adult	*Microtonus* sp.	Braconidae	Endoparasitoid
Pod midge	Egg	*Platygaster* (species A)	Platygastridae	Egg-larval endoparasitoid
	Egg	*Platygaster* (species B)	Platygastridae	? Egg-larval endoparasitoid
	Egg	*Inostemma* sp.	Platygastridae	? Egg-larval parasitoid
	Larvae	*Omphale clypealis*	Eulophidae	Endoparasitoid
	? Cocooned larva	? *Aphanogmus abdominalis*	Ceraphonidae	Endoparasitoid

<u>Pod midge</u>. Five species of parasitoid were reared from pod midge (**Table 3.1**). *Platygaster* (species A) was the most abundant parasitoid in winter oilseed rape, representing 96% of all parasitoids reared. In spring rape, *Omphale clypealis* (Thomson) was predominant, with 67% of parasitoids reared being of this species. *Platygaster* (species B), *Inostemma* sp. and ? *Aphanogmus abdominalis* (Thomson) were scarce.

3.1.4 *Discussion*

Agricultural monocultures are less diverse than natural ecosystems. Therefore, although many species can parasitise seed weevil and pod midge, only a few will be found on arable crops.

That *T. perfectus* was the most abundant parasitoid of seed weevil agrees with other UK studies (McKenna, 1972; Nasreldin, 1973), although in Switzerland Büchi (1993) found *M. morys* predominant. However, since their biologies are similar, for the purpose of practical biocontrol there is unlikely to be much difference. Generally, the most commonly reared parasitoids of seed weevil are those attacking larvae. In Germany, however, Godan (1959) found that up to 90% of weevil eggs were parasitised by the mymarid *Mymar autumnalis* (Förster), whereas Bonnemaison (1957) found that the braconid *Perilitus (= Microtomus) melanopus* (Ruthe), a parasitoid of adult weevils, was most important near Paris, France.

Identification of midge parasitoids has been hampered by their intrinsically difficult taxonomy. *Platygaster* (species A) does not correspond to any UK species cited as attacking pod midge; it is either a new UK record or a new, previously unrecognised (perhaps even undescribed) parasitoid of pod midge. *O. clypealis* has previously been cited as a parasitoid of pod midge, although it was not considered important in control (Laborius, 1972). As both *Platygaster* (species A) and *O. clypealis* are endoparasitoids, they are undetectable during pod dissections and explains why no such parasitoids were recorded in the multi-site experiments (**Section 2**) or pest monitoring surveys (see **Section 4**).

For biocontrol strategies, it is often necessary to concentrate on a few parasitoid species. In this study *T. perfectus*, *Platygaster* (species A) and *O. clypealis* were the most abundant and, therefore, have greatest potential. However, other parasitoids do attack these pests and these may, sometimes, be important.

3.2 Life-cycles of the major parasitoids

3.2.1 *The seed weevil parasitoid* Trichomalus perfectus *(Fig. 3.1)*

Female *T. perfectus* enter the winter rape crop 2–3 weeks after the peak migration of the seed weevil. On the crop the female feeds on nectar to provide an energy source and then seeks seed weevil larvae in which to lay her eggs and probably also for host-feeding. Host-feeding is a common strategy for some types of parasitoid, in which the female parasitoid feeds from the hosts to obtain protein to develop her eggs. Several authors (McKenna, 1972; Jourdheuil *et al.*, 1974) have suggested that it occurs in *T. perfectus*. Further evidence for its occurrence has been obtained in this study from both field observations (Murchie, 1995) and experimental work (see **Section 2**). During host-location the female walks up and down the pod, drumming with her antennae; the latter contain chemoreceptors sensitive to chemicals present in larval frass (Dmoch & Rutkowska-Ostrowska, 1978). On finding a seed weevil larva, the parasitoid arches her body and draws the abdomen forward until its tip touches the pod. The ovipositor, which is held along the abdomen, pierces the pod and the abdomen is returned to horizontal. With a waggling motion of her abdomen the parasitoid slowly works the ovipositor through the pod wall. The parasitoid then stings the weevil larva several times before laying a single egg on it.

After hatching, the parasitoid larva feeds from the host, eventually consuming it completely. The development of *T. perfectus* takes 2–3 weeks. On average, the egg stage lasts three days, the larva for seven and the pupa for eight (Dmoch & Klimek, 1975). The mature parasitoid larva pupates inside the pod, with the adult parasitoid eventually chewing its way out. Mating occurs shortly after emergence. The adult parasitoids leave the rape crop before harvesting (Laborius, 1972); females, but not males, have been found to overwinter in evergreen foliage and in sheltered nooks and crannies.

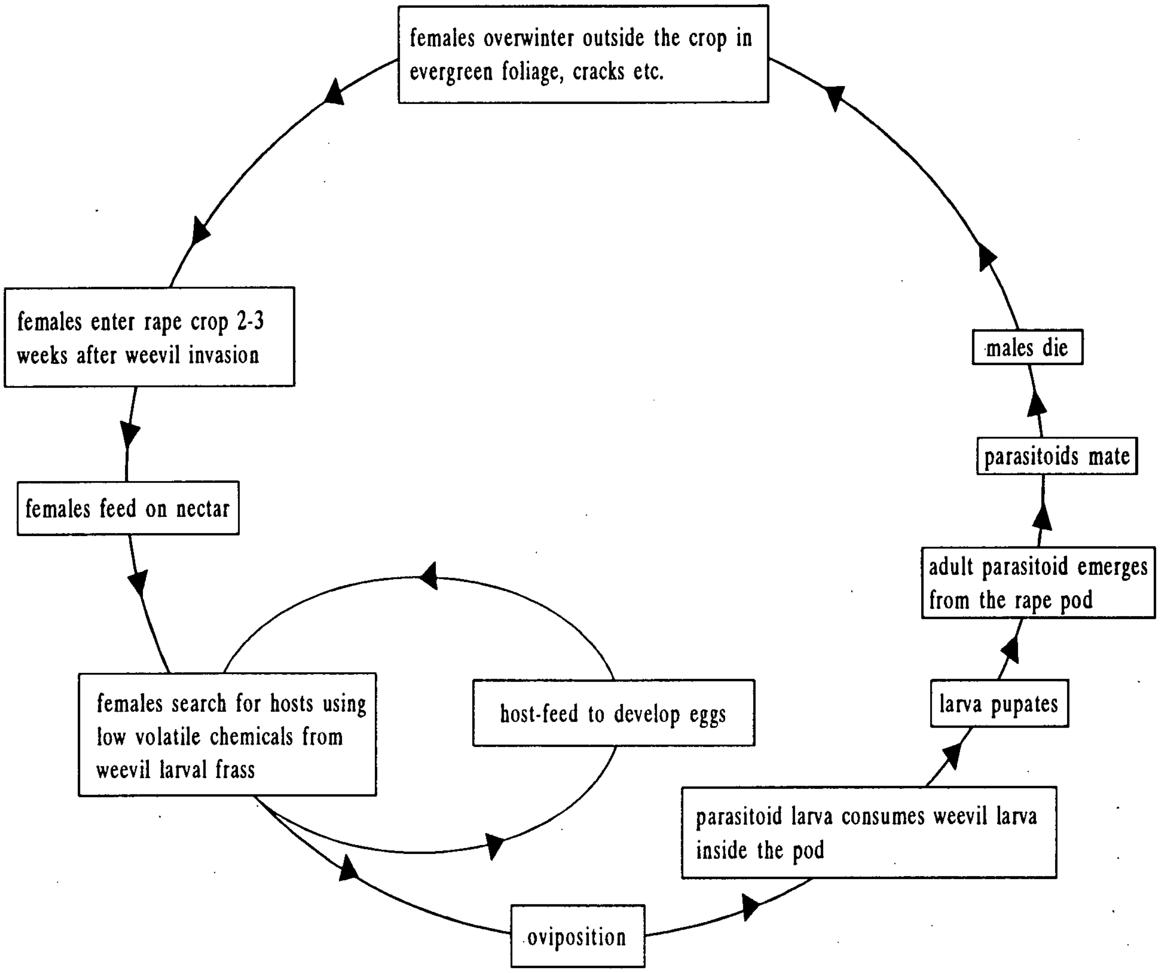

Fig. 3.1 Life-cycle of *Trichomalus perfectus.*

3.2.2 *The pod midge parasitoid* Platygaster *(species A) (Fig. 3.2)*

The general biology of platygastrids attacking pod midge is poorly known. Both male and female *Platygaster* (species A) overwintered in the soil inside midge cocoons. Mating occurred shortly after emergence. The parasitoids then entered the rape crop to search for midge eggs within pods. The methods of host location are not known but it is likely that parasitoids use host-plant volatiles as olfactory cues (**Section 3.5**). Oviposition has not been described but observations suggest that the parasitoid, to pierce the pod, utilizes the same damage as the egg-laying pod midge. The parasitoid has a long and mobile ovipositor and attacks many eggs within the pod. The development of the parasitoid egg is delayed until the midge larva burrows into the soil and forms a cocoon, whereupon the parasitoid develops within its larval host. Parasitoids emerged from the soil after *c.* 41 days compared with *c.* 14 for the midge although, as with midges, some parasitoids entered diapause. The number of generations of *Platygaster* (species A) is not known.

3.3 The impact of *Trichomalus perfectus* on seed weevil

3.3.1 *Introduction*

In assessing the impact of *T. perfectus* on the damage caused by seed weevil to rape pods, two components of parasitoid control must be considered: a) direct consumption of the weevil larva by the parasitoid and b) reduction of weevil larval damage to seeds within pods following parasitisation, as parasitised weevil larvae stop feeding.

The aims of this study were: a) to quantify the level of parasitism of seed weevil; b) to determine whether parasitism reduces pod damage by weevil larvae.

3.3.2 *Materials and methods*

Oilseed rape pods at GS 6.4 were dissected and live, dead or parasitised weevil larvae and weevil exit holes counted. Parasitism was calculated as: the number of parasitised

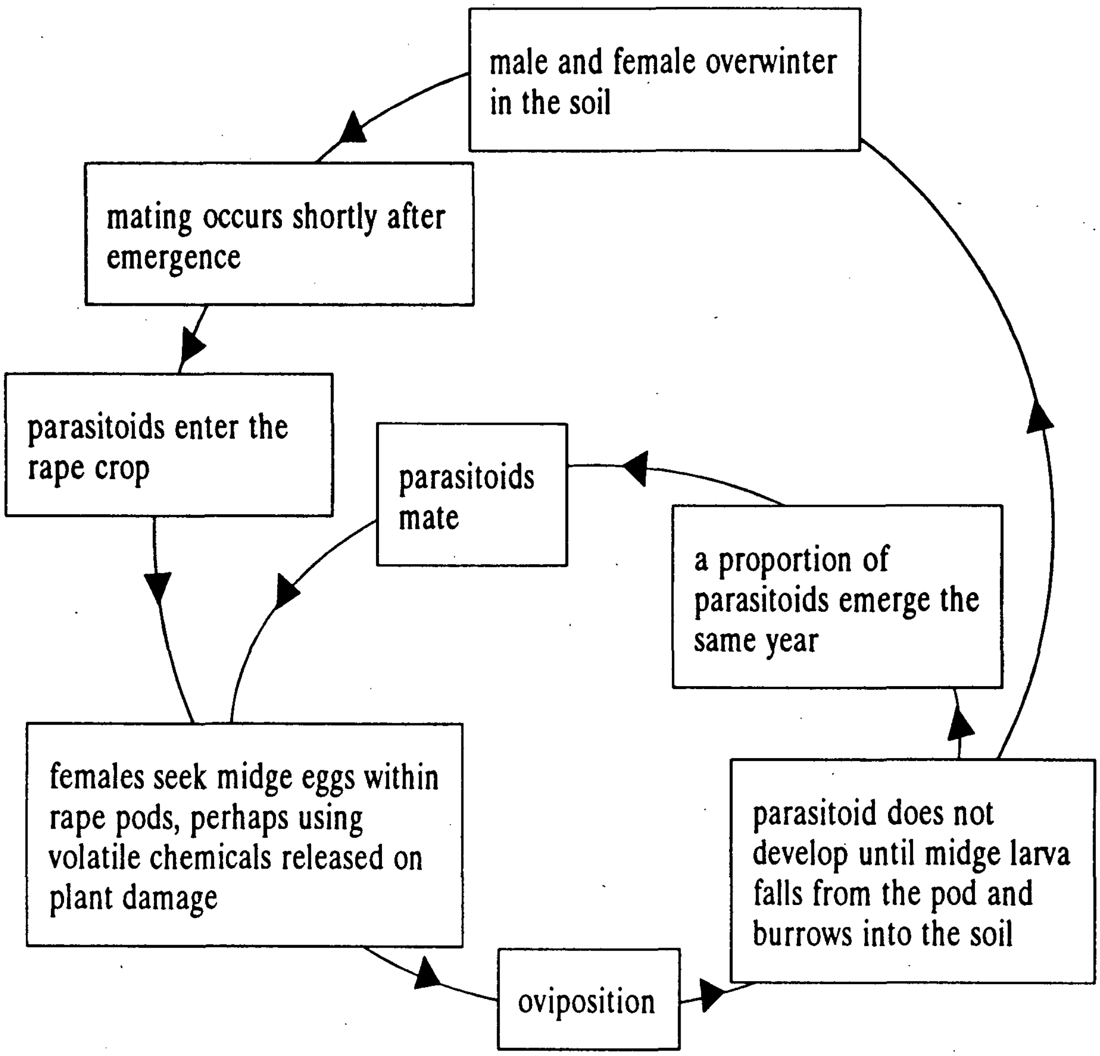

Fig. 3.2 Life-cycle of *Platygaster* (species A).

larvae divided by total number of weevil larvae (live, dead and parasitised) plus weevil exit holes.

During pod dissections the seeds eaten by weevil larvae that were unparasitised or parasitised by *T. perfectus* were counted.

3.3.3 *Results*

Parasitism. Parasitism by *T. perfectus* was high, with 39–73% of seed weevil larvae in winter rape crops parasitised and 25% of larvae in spring rape parasitised (**Table 3.2**).

Table 3.2 *Parasitism of seed weevil by* T. perfectus *in unsprayed oilseed rape, 1992–1994.*

Year	*Crop*	*Site*	*% parasitism*
1992	Winter rape	IACR Woburn, Bedfordshire	73
1993	Winter rape	IACR Rothamsted, Hertfordshire	65
1994	Winter rape	IACR Rothamsted, Hertfordshire	51
1994	Winter rape	IACR Rothamsted, Hertfordshire	39
1993	Spring rape	IACR Rothamsted, Hertfordshire	25

Seeds eaten by weevil larvae. The mean number of seeds eaten by parasitised weevil larvae was 3.2 compared with 5.2 when larvae had successfully emerged from pods. Parasitised weevil larvae caused 38% less damage than healthy larvae with, occasionally, weevil larvae being attacked before they had even consumed one seed.

3.3.4 *Discussion*

Because, parasitoids are dependent on their hosts for continued survival, it is uncommon for a naturally occurring parasitoid to achieve 100% control of a pest. However, most pest control strategies on arable crops require pest numbers to be below an economically damaging threshold. Parasitoids can provide an effective means of pest control where an equilibrium between pest and parasitoid is attained, such that pest numbers do not exceed their economic damage threshold levels.

Clearly, *T. perfectus* had a large impact on weevil populations in the UK oilseed rape crops investigated. Similar levels of parasitism have been reported elsewhere in Europe, e.g. 43% in Germany (Laborius, 1972), 70% in Poland (Dmoch and Klimek, 1975), 70% in France (Lerin, 1987). Besides host larval parasitisation, there is evidence that parasitoids may be exerting additional mortality by host-feeding (see **Sections 2 and 3.2.1**). The extent to which this behaviour occurs in *T. perfectus* is unknown but it may be important in biological control. For example, some parasitoids may inflict greater mortality through host-feeding than by actual parasitisation (Flanders, 1953).

Direct mortality of weevil larvae, leading to a reduction in the weevil population for the following year, is the most important consequence of parasitism. However, parasitised larvae also cause less damage to developing seeds in the current year and this should be considered when assessing their impact on weevil damage to oilseed rape.

The maintenance of *T. perfectus* populations has previously been neglected in the formulation of pest control strategies for UK oilseed rape crops, despite performing a valuable and important role in regulating pest numbers. Given the high levels of parasitism that can be achieved naturally, pest control strategies should recognise their role and endeavour to enhance their effectiveness.

3.4 The impact of *Platygaster* (species A) on pod midge

3.4.1 *Introduction*

The rationale for estimating the impact of parasitism on pod midge is different from that for seed weevil. Pod midge normally has three generations per year, with some larvae emerging as adult midges the same year and others entering diapause to emerge as adults during subsequent years. Estimates of parasitism, therefore, require samples of pre-and post-diapause midges. The biology of *Platygaster* (species A) is also different from that of *T. perfectus*. Since *Platygaster* (species A) does not develop until the midge larva is mature, there is no reduction in pod midge larval feeding. There are no records of host-feeding in Platygastridae (Jervis & Kidd, 1986). The aim of the present study was to estimate parasitism of pod midge by *Platygaster* (species A) during the season and pre- and post-diapause.

3.4.2 *Materials and methods*

Winter oilseed rape plants were collected from the field at weekly intervals from 7 June to 28 June. Mature pod midge larvae that dropped from plants were reared in moist sand within glass vials. These were kept at 18°C until mid-September when they were transferred to 5°C for 120 days (to mimic winter temperatures and break midge diapause), whereupon they were returned to 18°C. Vials were examined at regular intervals and emergent midges and parasitoids counted.

3.4.3 *Results*

Parasitism of pod midge varied considerably, being greater post- as compared with pre-diapause (**Table 3.3**). Maximum parasitism was 64% for post-diapause midges collected on 7 June, with greatest parasitism for any one sampling date of 25% for midges collected on 14 June. Mean parasitism for the four sampling dates was 16%.

Table 3.3 *Parasitism of pod midge during June 1994 at IACR Rothamsted.*

	Sampling date			
Parasitism	*7 June*	*14 June*	*21 June*	*28 June*
Pre-diapause	5	11	2	2
Post-diapause	64	52	19	20
Total	12	25	9	15

3.4.4 *Discussion*

As with the seed weevil, parasitoids are clearly an important cause of pod midge mortality. The variation in parasitism of pod midge (from 2 to 64%) emphasises the importance of monitoring parasitoids both throughout the season and post-diapause. Estimation of parasitism of a multivoltine insect based on samples taken from one generation only is clearly inadequate.

It is not known why parasitism is greater post-diapause than pre-diapause but this may be connected with the longer development of the parasitoid. That a greater proportion of parasitoids than pod midges diapause in the soil is relevant to biocontrol strategies because post-harvest soil cultivation may kill both insects. Research on pollen beetle parasitoids showed that four times as many emerged from direct-drilled plots compared with disk-harrowed or ploughed plots (Nilsson, 1985).

Assessing the impact of *Platygaster* (species A) on pod midge is more complicated than for a univoltine pest. The impact of parasitism cannot be expressed as a single figure because not only does the percentage parasitism vary with the time the sample is taken but its value to the farmer can change as well, e.g. high levels of parasitism in the first generation may prevent a build-up of pod midges later in the season. However, the overall mean parasitism of 16% indicates that, in combination with *T. perfectus*, *Platygaster* (species A) does have potential in integrated pest management.

3.5 Monitoring parasitoids, using traps baited with semiochemicals

3.5.1 *Introduction*

Some of the pests of oilseed rape have been shown to respond to isothiocyanates (abbreviated in the text to NCS), the breakdown products of glucosinolates, which are released at sites of plant damage (e.g. Free & Williams, 1978; Bartlet *et al.*, 1993). The pests use these chemical cues to locate a host plant for food or oviposition. At IACR Rothamsted, these compounds are currently being used to develop monitoring systems for rape pests (Blight *et al.*, 1995; Smart *et al.*, 1995). Parasitoids often use plant-derived chemical cues to locate host habitats but the responses of the parasitoids to chemicals from the oilseed rape plant have not been studied previously.

The aim of this study was to investigate the responses of seed weevil, pod midge and their parasitoids to isothiocyanates, to establish whether these chemicals might be candidates for use in developing a trap monitoring system for such parasitoids.

3.5.2 *Materials and methods*

Yellow flight traps (**Fig. 3.3**) were designed specifically for use in this study because the sorting of water traps is time-consuming and, in the latter, small insects often become macerated. Each trap was mounted at crop canopy height and the insects collected in the jar containing 70% alcohol. The lure, mounted inside the funnel unit, consisted of a cellulose sponge impregnated with NCS and sealed in a polyethylene bag. Allyl-NCS and 2-phenylethyl NCS were used as chemical baits (at two release rates) because they have previously been used to trap crucifer-feeding insects and are commercially available. Release rates were altered by using different sizes of sponge and/or different thicknesses of polyethylene bags. Nominal release rates were: allyl-NCS 'low' release rate 11.6–12.5 mg/day, 'high' release rate 39.9–53.3 mg/day; 2-phenylethyl NCS 'low' release rate 1.4–2.0 mg/day, 'high' release rate 9.8–12.7 mg/day. The allyl-NCS lures were replaced with new ones after 4 weeks, on 15 July 1994, whereas the 2-phenylethyl lures were left unchanged throughout the experiment.

Traps were baited with one of the above treatments or left unbaited ('blank'). They were placed in winter oilseed rape at IACR Rothamsted, arranged in a 5 × 5 Latin square with a minimum distance of 10 m between traps, from 17 June until 5 August 1994. Traps were emptied weekly, catches stored in fresh 70% alcohol and pod midges, seed weevils, *Platygaster* (species A), *O. clypealis* and female *T. perfectus* counted.

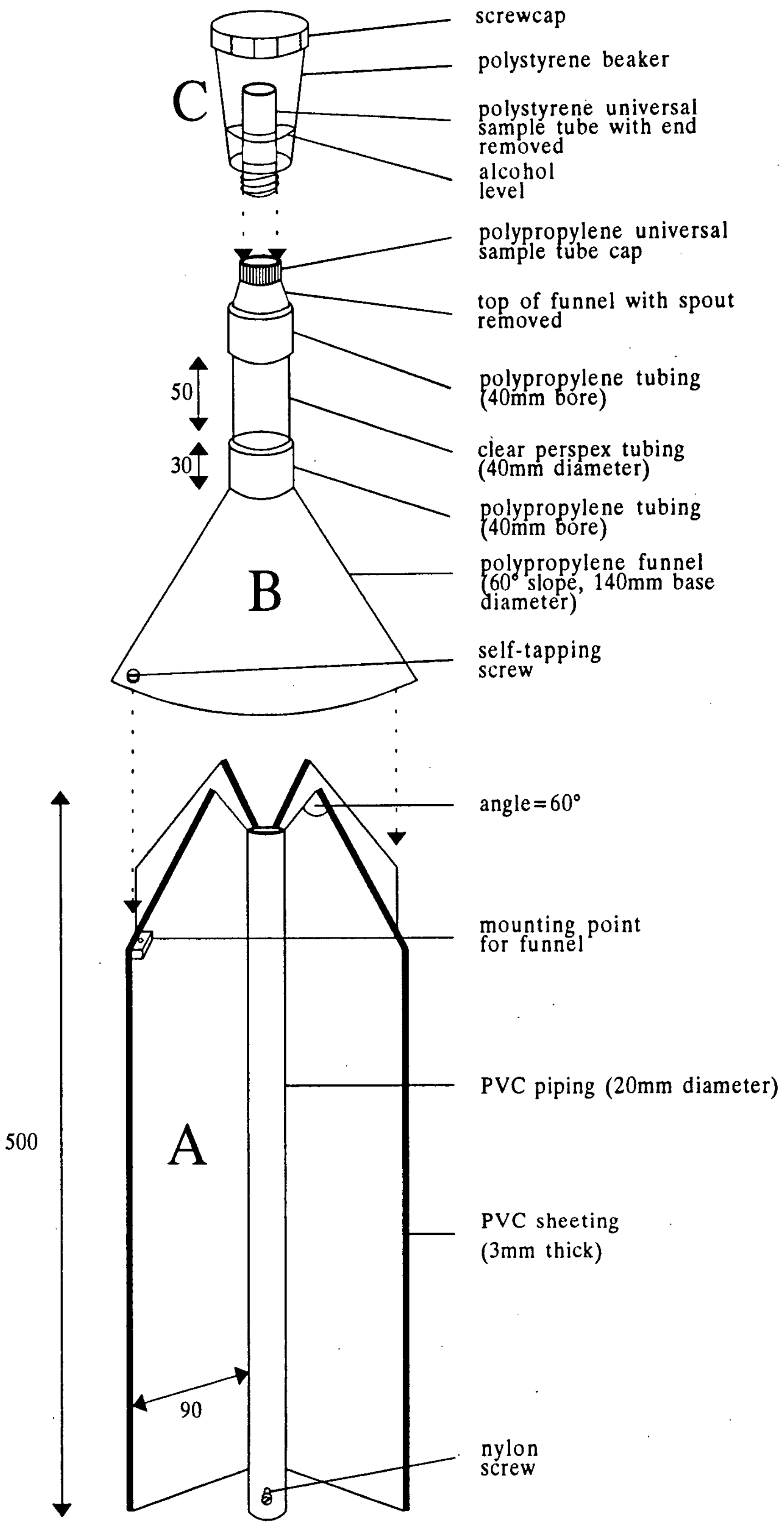

Fig. 3.3 Diagram of yellow flight trap, showing fins (A), funnel unit (B) and collecting jar (C). Sizes are in millimetres but not to scale.

3.5.3 *Results*

The pest and parasitoid catches in response to NCSs are presented in full for the week of 15–22 July only, to serve as an example of the data obtained (**Fig. 3.4**). The complete data set with probability values for significance are presented in Murchie (1995).

More male pod midges were caught in traps baited with allyl-NCS than with 2-phenylethyl NCS or 'blank', with greater numbers caught in traps baited with a 'low' compared with a 'high' release rate. Although few female pod midges were attracted, of the ten females caught throughout the experiment, nine were caught in traps baited with allyl-NCS and only one in traps baited with 2-phenylethyl NCS.

More male and female *Platygaster* (species A) were caught in traps baited with 2-phenylethyl NCS than allyl-NCS with the 'high' release trap catching more than the 'low'. More male than female *Platygaster* (species A) were caught.

On 29 July–5 August, more female *O. clypealis* were caught in traps with allyl-NCS than 2-phenylethyl or 'blank', with greater numbers being caught in traps baited with the 'low' compared with the 'high' release rate.

Few seed weevils were caught before 29 July but during 29 July–5 August more seed weevils were caught in traps baited with 2-phenylethyl NCS than with allyl-NCS or 'blank'.

Few female *T. perfectus* were caught in traps. Male *T. perfectus* were not counted, although large numbers of male pteromalids (possibly *T. perfectus*) were caught from week 22–29 July onwards.

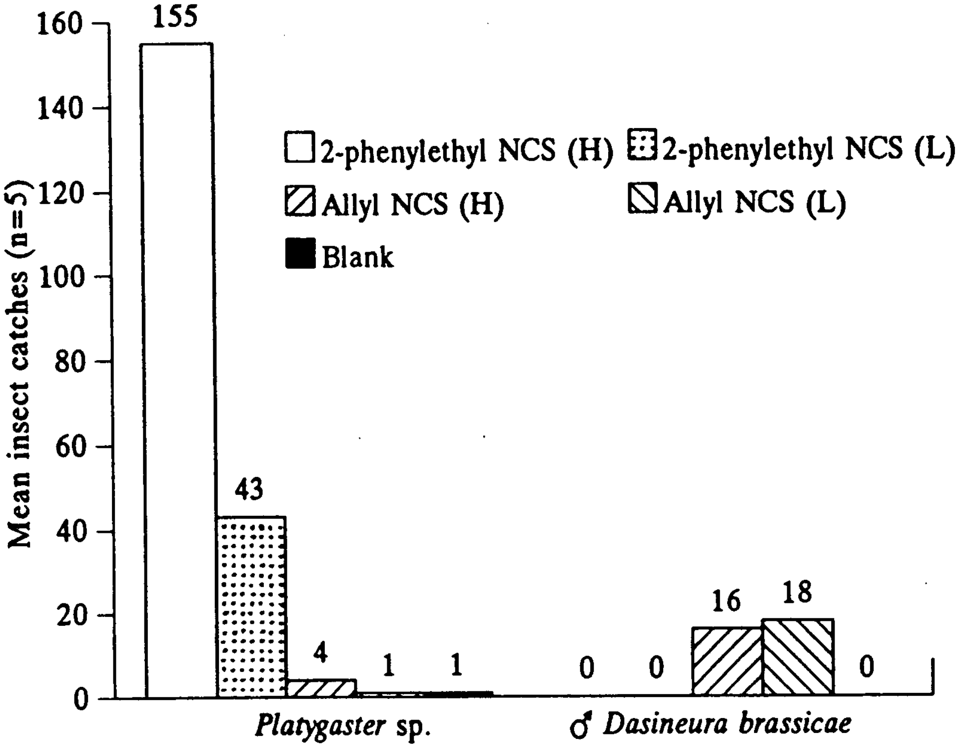

Fig. 3.4 Pest and parasitoid catches in flight traps for one week (15-22 July 1994): (H) high and (L) low release rate.

3.5.4 *Discussion*

Yellow flight traps of this new design, baited with NCSs, proved a highly effective means of trapping male pod midges and *Platygaster* (species A) (the main pod midge parasitoid).

Attraction of male pod midges to allyl-NCS agrees with Evans (1991), whereas Lerin (1984) found that male pod midges seemed to be attracted to phenyl (presumably 2-phenylethyl) NCS. Usually, more males were caught in traps with a 'low' rather than a 'high' release rate. That males respond so strongly to allyl-NCS but that few females were caught is puzzling, and was also noted by Evans (1991); more work is needed to determine the mechanisms behind these responses.

Both male and female *Platygaster* (species A) were attracted to 2-phenylethyl NCS, the first time that a parasitoid has been shown to respond to an NCS other than allyl-NCS. As both sexes responded, the purpose of this behaviour is, as yet, unclear and not solely to detect oviposition sites.

Adult seed weevils were caught late in the season and were thus new-generation weevils. Seed weevil adults have previously been shown to respond to 2-phenylethyl NCS (Blight *et al.*, 1989; Evans, 1991).

At present, there is no monitoring system for pod midge in oilseed rape. Farmers make the decision to spray on the basis of seed weevil counts and previous history of midge attack (Cooper & Lane, 1991). This experiment has shown that yellow flight traps, baited with appropriate NCS, have potential for developing a convenient means of monitoring pod midge and *Platygaster* (species A) directly, which could lead to a more refined pest management strategy.

3.6 Monitoring parasitoids, using traps baited with pod midge sex pheromone

3.6.1 *Introduction*

Virgin female brassica pod midge, while extending their ovipositors, release a sex pheromone that attracts males of the same species (Williams & Martin, 1986; Isidoro *et al.*, 1992). Many parasitoids of lepidopteran eggs and scale insects are attracted to the sex pheromones of their hosts and there is one record of a platygastrid egg/larval parasitoid responding to a cecidomyiid sex pheromone (Isidoro & Bin, 1988).

The aim of this experiment was to determine whether *Platygaster* (species A) adults were attracted to traps baited with newly emerged virgin female pod midges releasing sex pheromone.

3.6.2 *Materials and methods*

Traps were cardboard delta traps (Oecos Ltd., Kimpton) with ventilated cages to hold female midges suspended under the ridge. Six pairs of traps were placed in a spring oilseed rape crop at IACR Rothamsted. Each pair consisted of a baited trap containing 15 virgin female pod midges and a blank trap, with a minimum of 5 m between traps. Traps were held slightly below the crop canopy, as *Platygaster* (species A) had been observed to search pods at this height. Traps were placed in the crop on 1 August and removed on 3 August 1994. Pod midge, female *Platygaster* (species A) and *O. clypealis* adults caught on the sticky plates of the traps were then counted.

3.6.3 *Results*

More male pod midges were caught in traps containing virgin female midges than in traps without midges ($P < 0.001$) (**Fig. 3.5**). Female pod midges were caught in similar numbers in baited and unbaited traps. All *O. clypealis* caught were female but they were caught in similar numbers in baited and unbaited traps. Three female

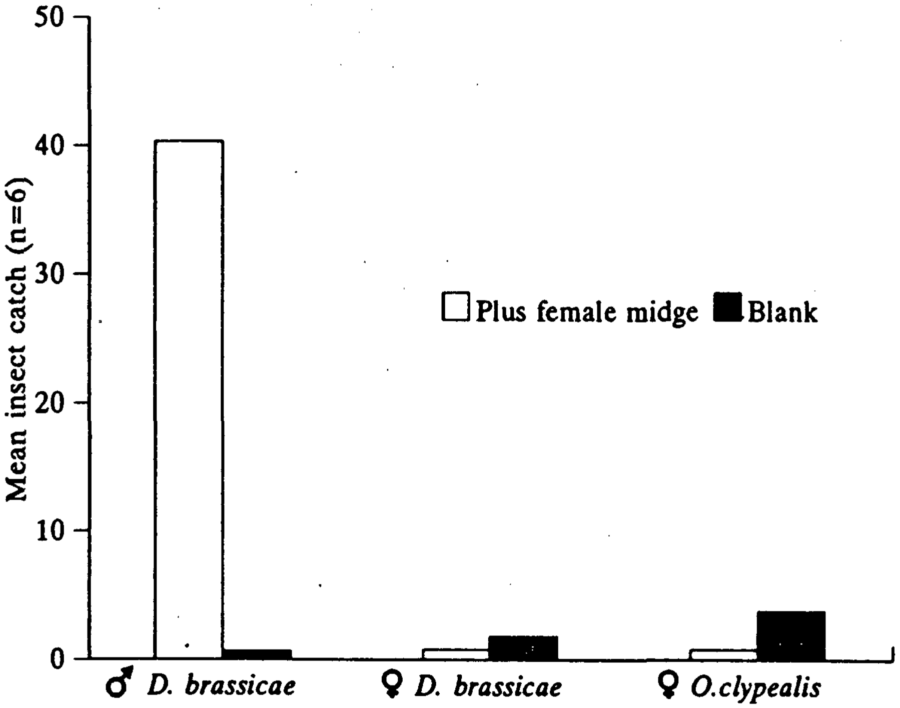

Fig. 3.5 Pest and parasitoid catches in delta traps baited with female midge sex pheromone (1-3 August 1994).

Platygaster (species A) were caught in the traps: two in baited traps and one in a 'blank' trap.

3.6.4 *Discussion*

Although virgin female pod midges confined to traps released their sex pheromone (Isidoro *et al.*, 1992) and attracted males of pod midge, neither female *D. brassicae* nor *O. clypealis* were attracted by the sex pheromone. Despite adults of *Platygaster* (species A) being observed in the crop at the time of the experiment, their density was unknown and the low numbers caught makes it impossible to determine if there is any response of this parasitoid to the sex pheromone of the pod midge.

3.7 Distribution of pests and parasitoids in an oilseed rape crop

3.7.1 *Introduction*

Many studies of the distribution of pests within oilseed rape crops considered differences in pest concentrations at the edges and centres of crops only. However, the crop environment across the field is a dynamic one, constantly and subtly changing, and insects may respond to these changes by feeding and/or ovipositing in different areas at different times.

The aim of this study was: a) to determine and quantify the distributions of pests and their parasitoids within a field of oilseed rape; b) to examine insect movement throughout the crop; c) to investigate spatial interactions between different species.

3.7.2 *Materials and methods*

Experimental procedure. Thirty yellow-bowl water traps were arranged on a grid, in and around a crop (1.2 ha) of winter oilseed rape situated beside a wood (a possible overwintering site for parasitoids) (**Fig. 3.6**). Traps were placed a maximum of 14 m apart and mounted at crop canopy height. They were emptied weekly, from 1 May

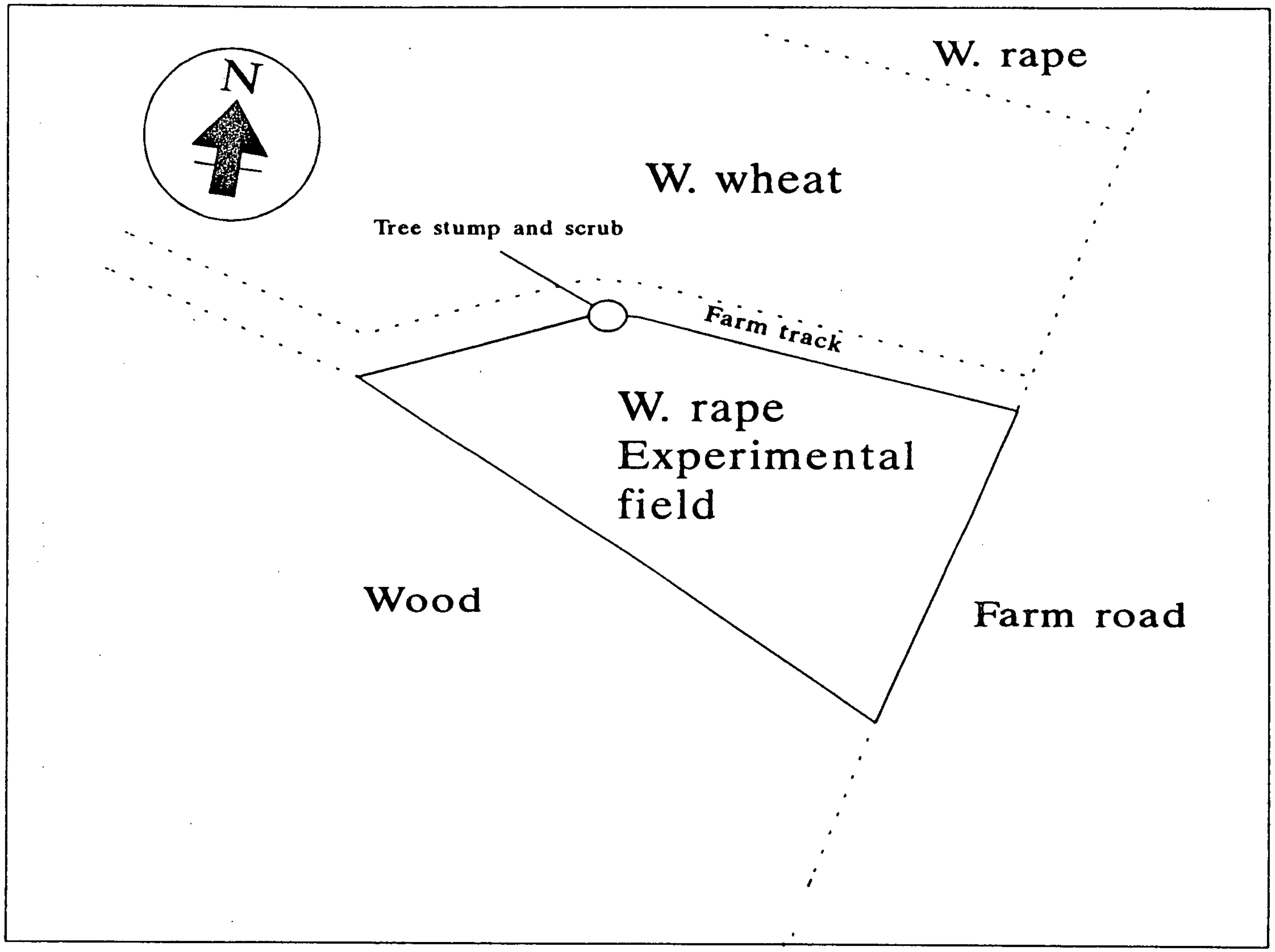

Fig. 3.6 Position of experimental field at IACR Rothamsted (not to scale).

until 10 July 1992, and catches stored in alcohol. Specimens of seed weevil, pod midge, female *T. perfectus* and female *Platygaster* (species A) were counted.

Analysis. Counts were entered into the Unimap 2000 program which interpolates the data to produce contour maps of insect distribution. Correlation analysis was used to examine relationships between different sets of data (counts).

3.7.3 *Results*

Maps. Examples of maps are presented for 5 June (growth stage 6.1) **(Figs 3.7–3.10)** and 26 June (GS 6.3) **(Figs 3.11–3.14)**. The full data set are presented in Murchie (1995). The field boundary is marked by the solid line, 'T' represents the position of a trap, values represent trap counts and contour lines are indicative of greater insect density/activity. Distributions are shown for: seed weevil, female *T. perfectus*, female pod midge and female *Platygaster* (species A).

Distribution throughout the field – 5 June 1992. Most seed weevil were caught at the northern edge of the field, with fewest trapped in the southern corner **(Fig. 3.7)**. *T. perfectus* were mostly caught in the centre of the field compared with the edges, apart from traps closest to the tree stump (a possible overwintering site) **(Fig. 3.8)**. Female pod midge were caught in low numbers but had entered the middle of the field **(Fig. 3.9)**. Although numbers trapped were low, the distribution of female *Platygaster* (species A) **(Fig. 3.10)** was similar to female pod midge.

Distribution throughout the field – 26 June 1992. More seed weevil were caught in traps at the edges compared to the centre, their distribution forming two longitudinal ridges along the northern and southern sides of the field **(Fig. 3.11)**. Conversely, *T. perfectus* were mostly caught in central traps with their distribution forming a longitudinal ridge through the middle **(Fig. 3.12)**. There were two areas of high pod midge density, one in the centre of the field and the other at the southern corner **(Fig. 3.13)**. Numbers of female *Platygaster* (species A) trapped were low but, as with female pod midge, they were distributed in two groups within the field **(Fig. 3.14)**.

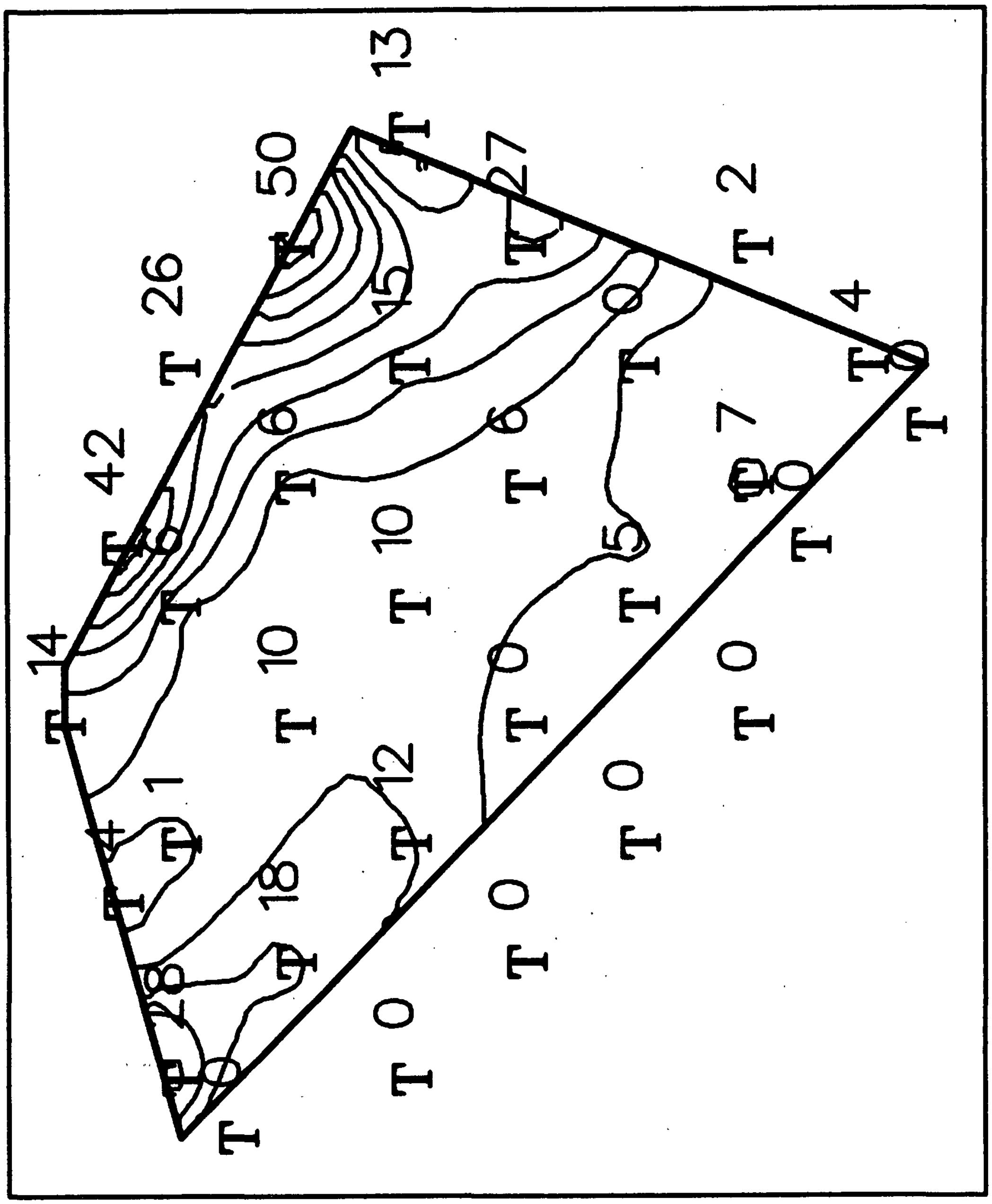

Fig. 3.7 Seed weevil distribution on experimental crop on 5 June 1992 (see text for description).

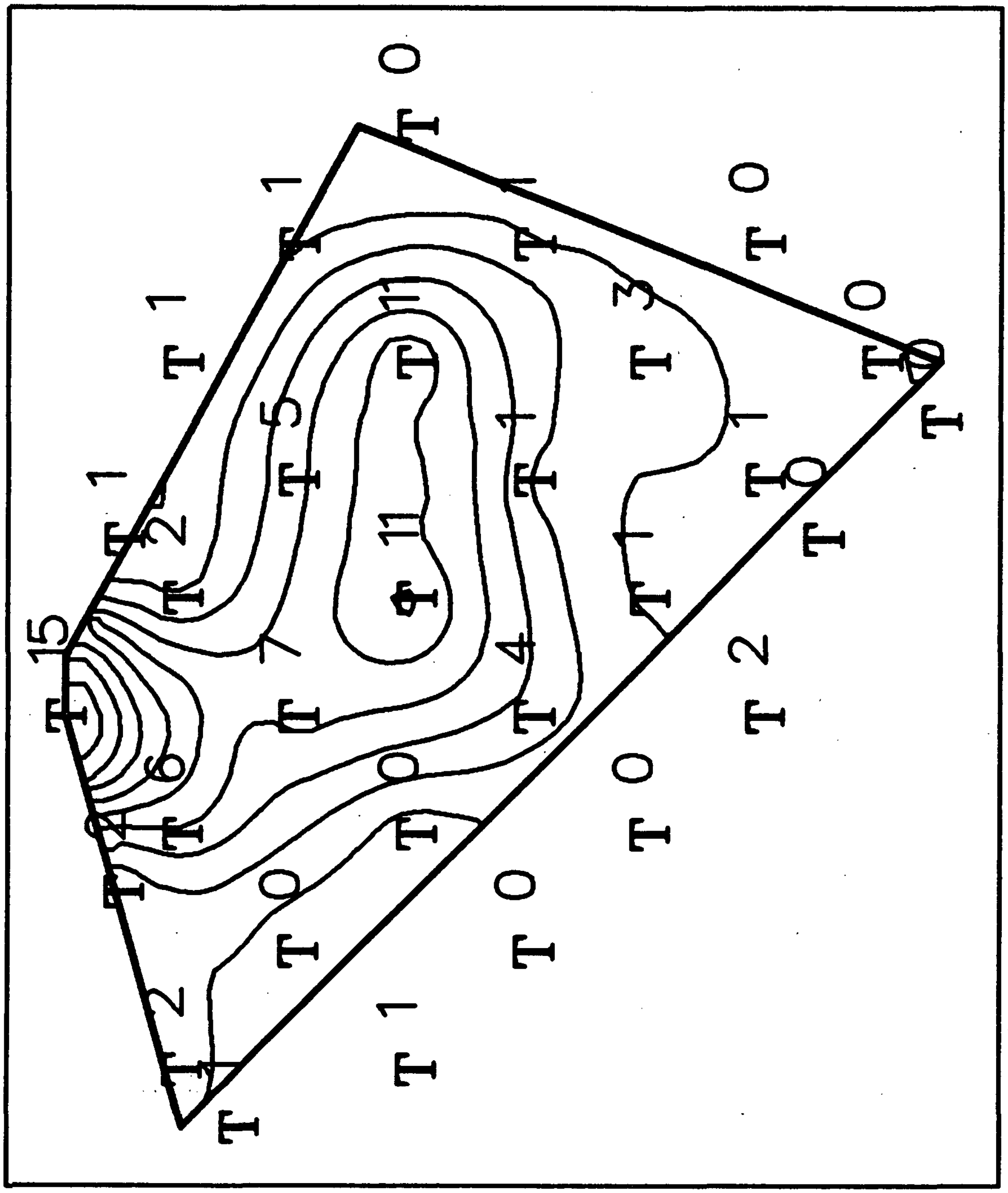

Fig. 3.8 Female *Trichomalus perfectus* distribution on experimental crop on 5 June 1992 (see text for description).

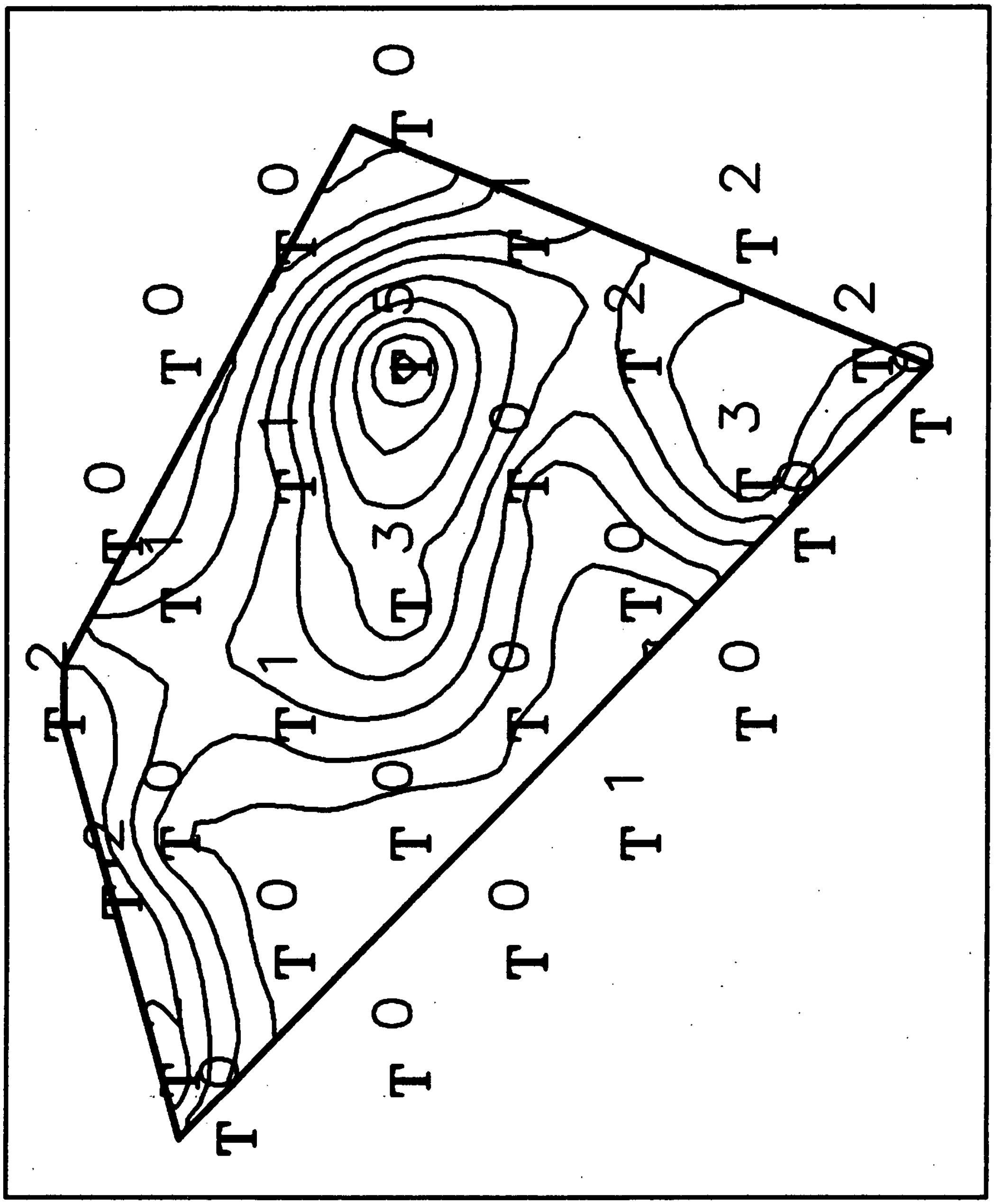

Fig. 3.9 Female pod midge distribution on experimental crop on 5 June 1992 (see text for description).

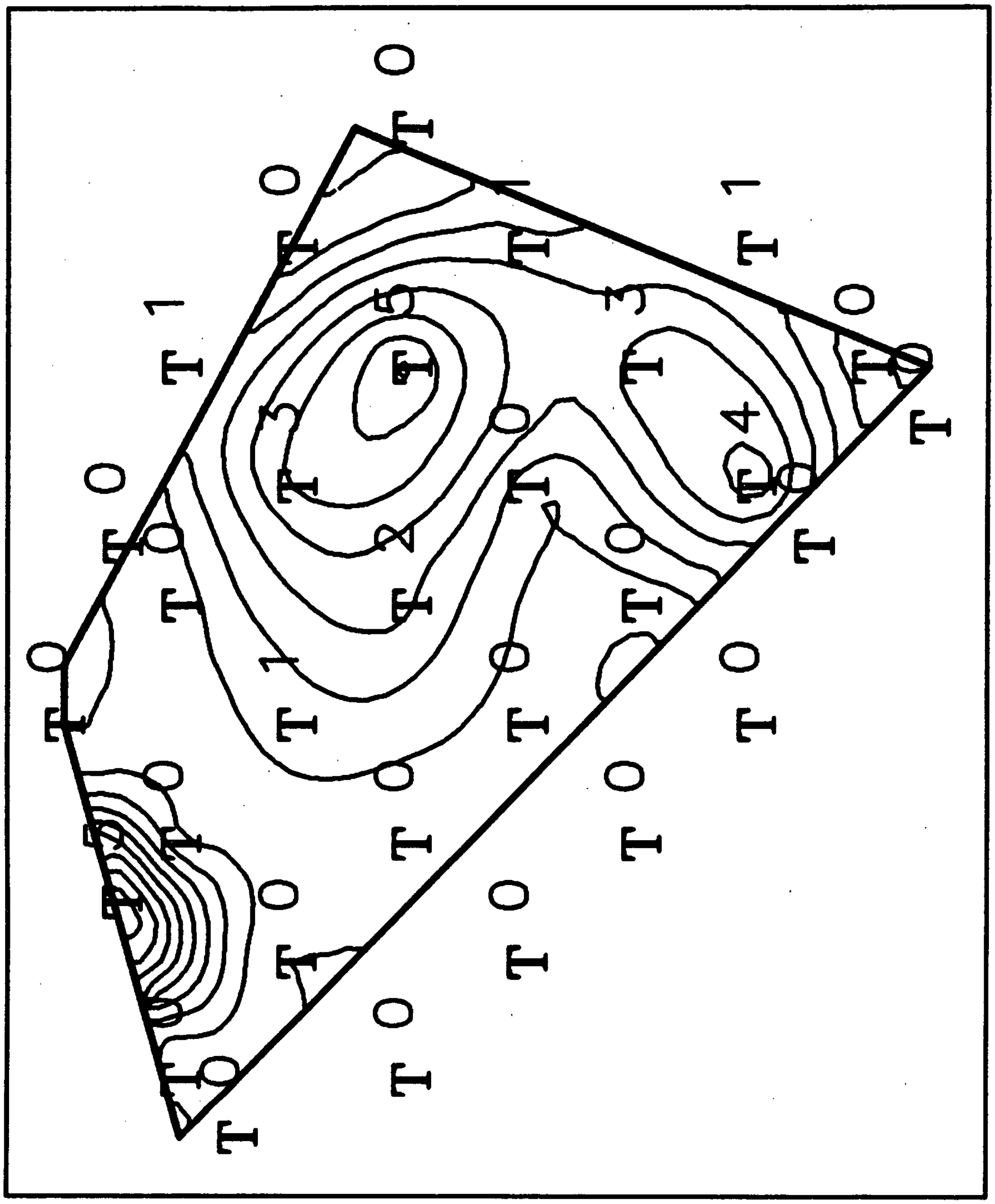

Fig. 3.10 Female *Platygaster* (species A) distribution on experimental crop on 5 June 1992 (see text for description).

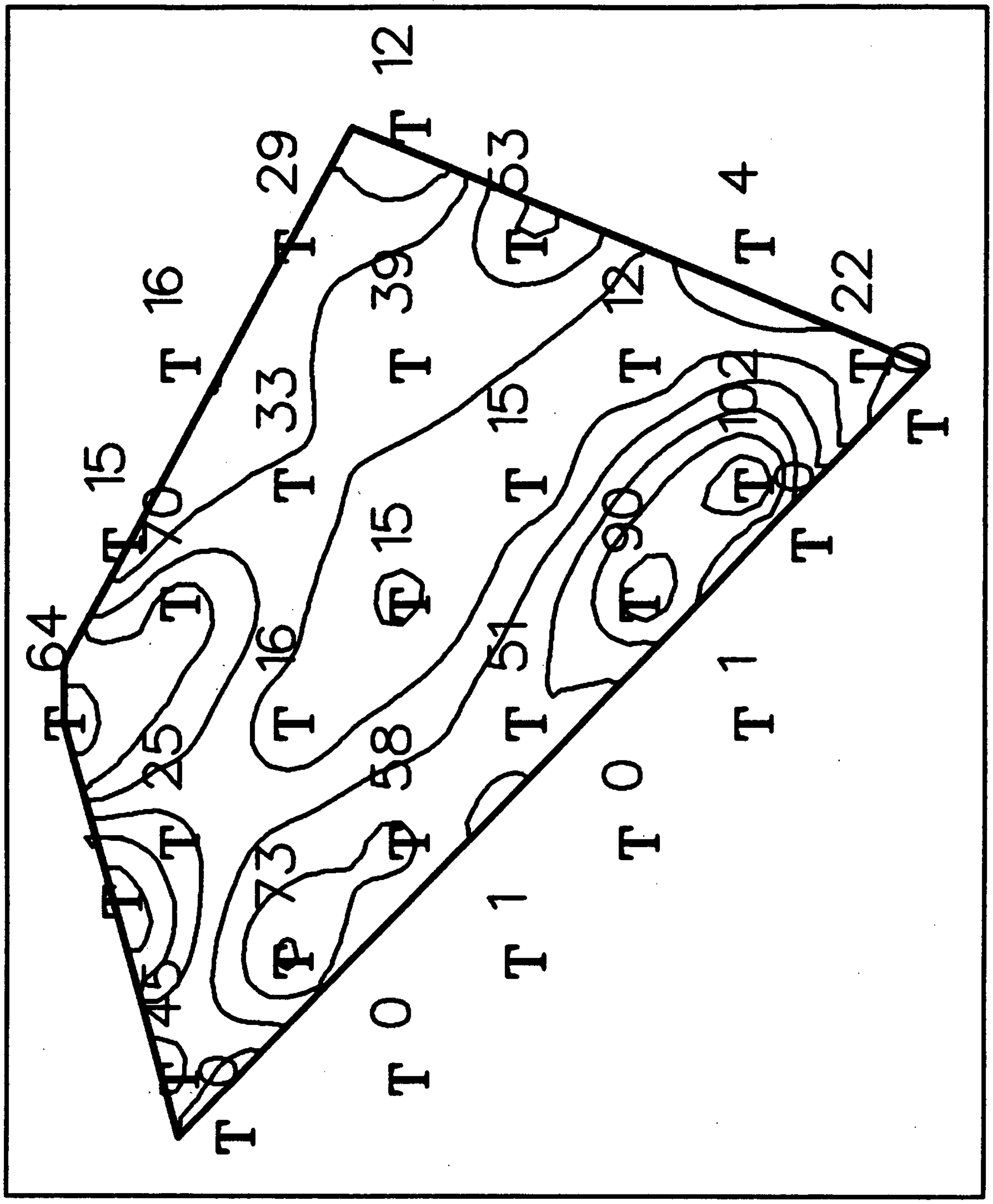

Fig. 3.11 Seed weevil distribution on experimental crop on 26 June 1992 (see text for description).

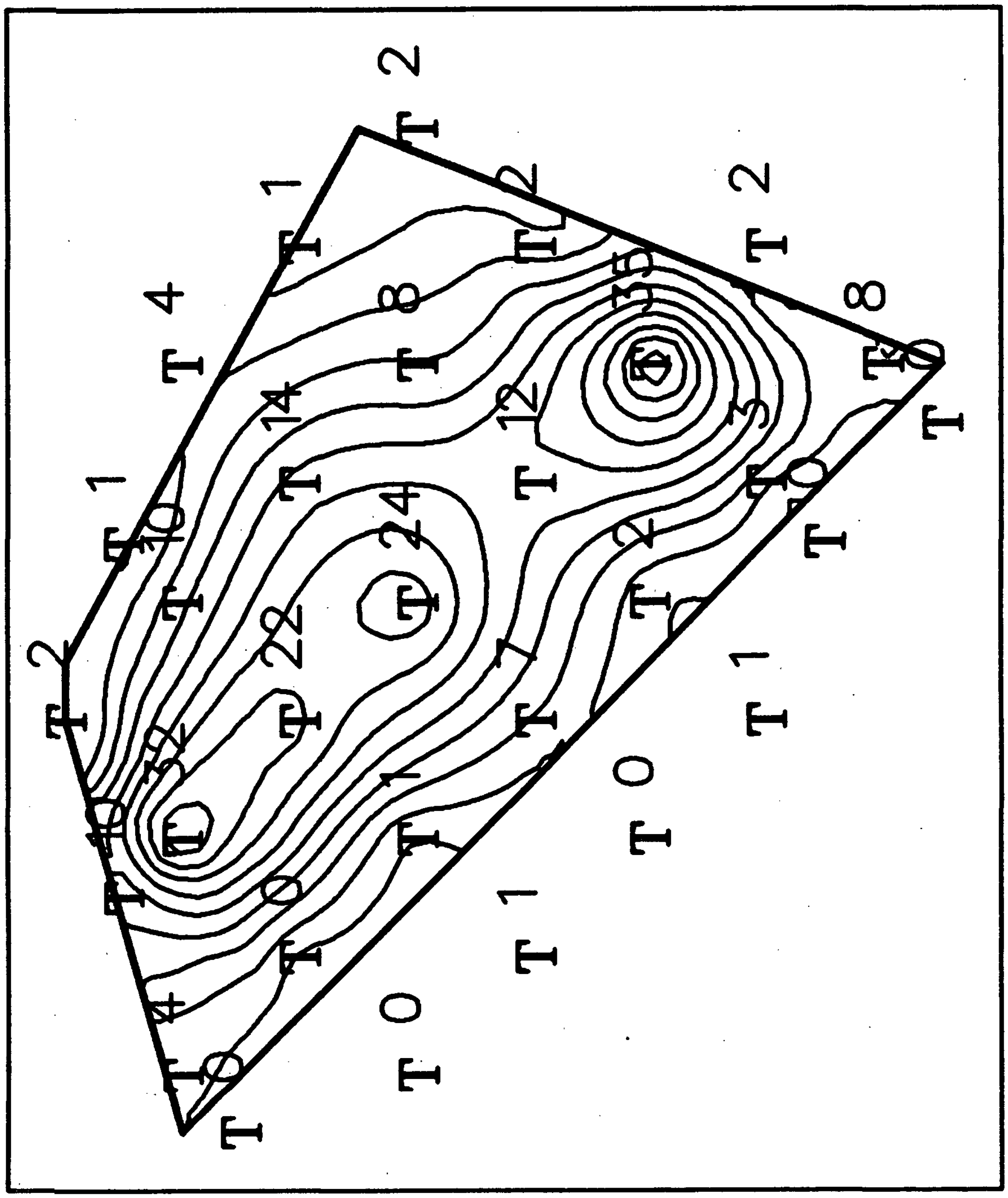

Fig. 3.12 Female *Trichomalus perfectus* distribution on experimental crop on 26 June 1992 (see text for description).

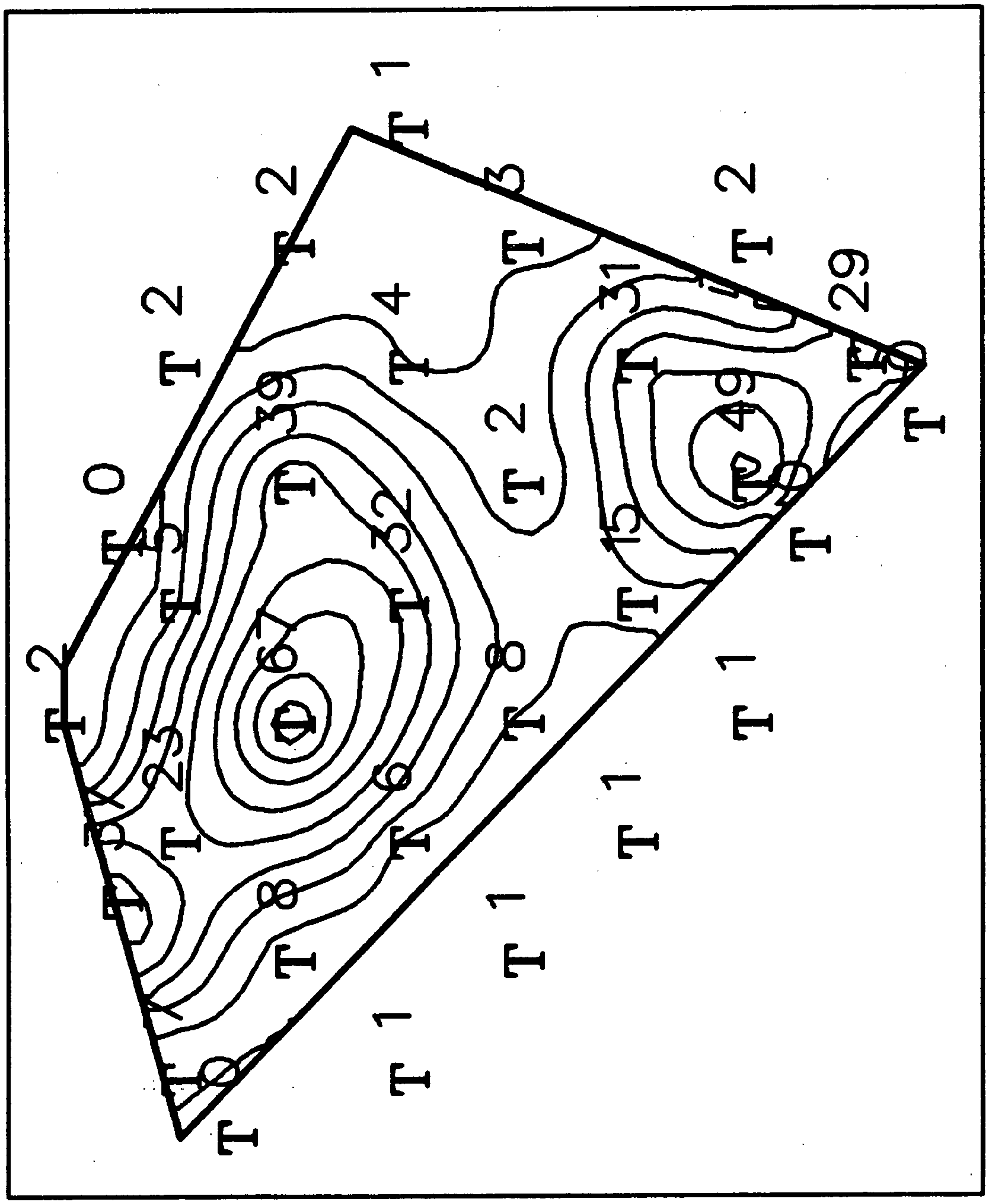

Fig. 3.13 Female pod midge distribution on experimental crop on 26 June 1992 (see text for description).

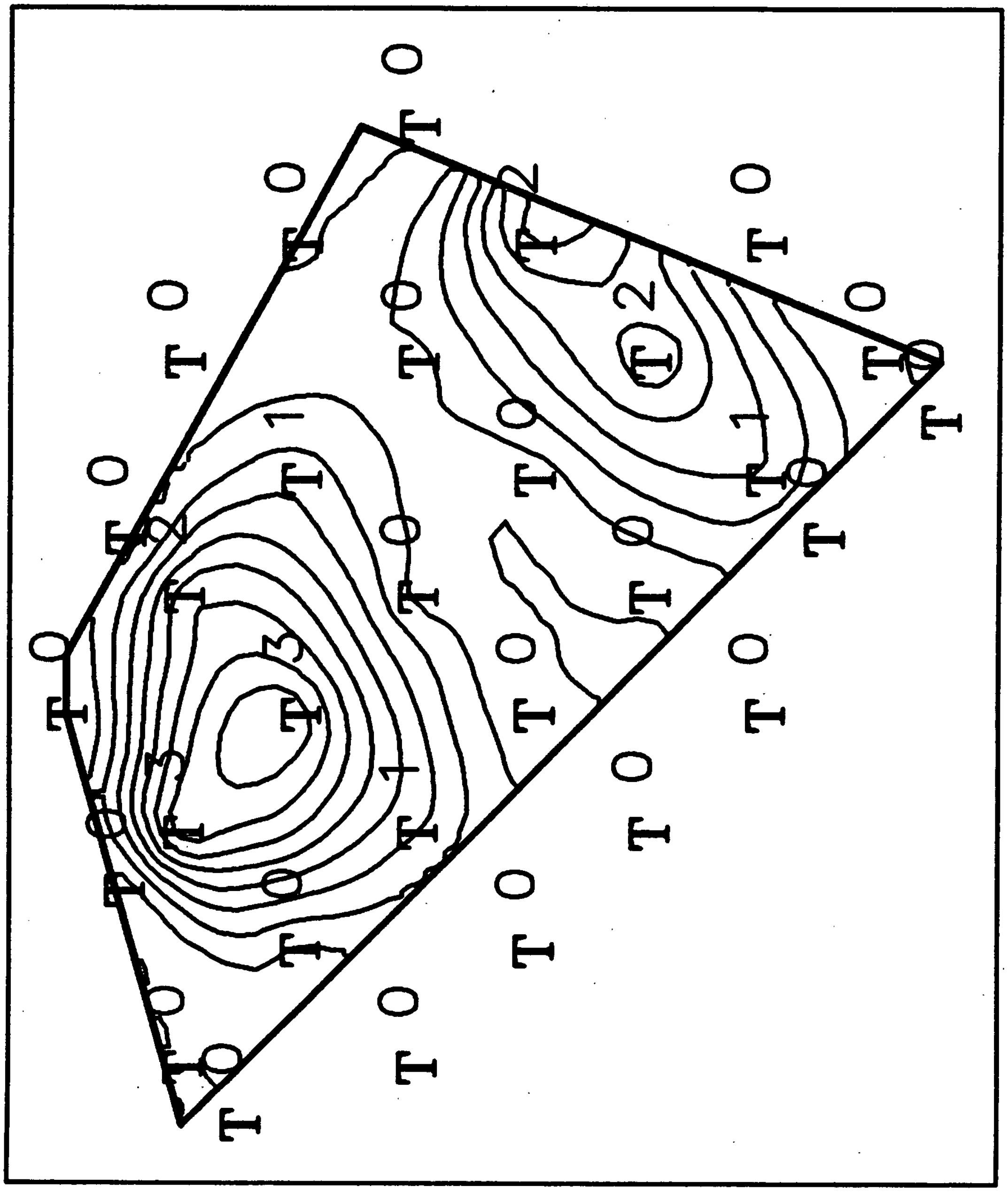

Fig. 3.14 Female *Platygaster* (species A) distribution on experimental crop on 26 June 1992 (see text for description).

Interaction between species. There was no correlation between trap counts of seed weevil and female pod midge. A negative correlation was found for counts of seed weevil and female *T. perfectus* (significant on 26 June). There was a positive correlation between counts of female pod midge and female *Platygaster* (species A) (significant on 5 June).

3.7.4 *Discussion*

Insect distribution throughout an arable field is dependent on many variables, including: the size and shape of the field; the position of the field relative to natural habitats and surrounding crops; the effects of wind and local microclimate. Two of the most important factors influencing distribution are the state of the crop and the behaviour of insects, in relation to the crop and each other.

On 5 June, the crop was at GS 6.1, with seeds in pods beginning to develop. At this stage, seed weevils were migrating into the field and starting to oviposit into pods. The experimental crop was less developed, compared with a neighbouring field, and the map for this date shows weevil immigration from the nearby rape crop (**Fig. 3.7**). Since there were no weevil larvae, *T. perfectus* were not searching for hosts and were probably still migrating into the crop from overwintering sites. Female pod midges caught in traps had migrated into the crop from their emergence sites. It is suprising that so many were trapped in the centre of the crop, because Free & Williams (1979) found pod midges concentrated at field edges. It is possible that the experimental field was too small for pod midge to exhibit an edge effect. Adults of *Platygaster* (species A) are likely to have emerged from the same place as pod midges and had entered the crop to parasitise midge eggs.

Three weeks later, on 26 June, pods were almost fully developed and the rate of weevil oviposition was decreasing. Weevils were distributed around the edges of the field, probably because these areas were backward and there were still suitable pods for oviposition. Weevil larvae were present inside pods and *T. perfectus* were searching for them, resulting in a distribution of *T. perfectus* likely to be similar to that of weevil larvae. More pod midges were caught than on 5 June; these were second-generation midges that had emerged from the soil below the crop.

It is surprising, given the dependence of pod midge on seed weevil for oviposition sites (Sylvén, 1949), that there was no spatial relationship between the two pests. Perhaps, for the comparatively low numbers of pod midge, there was sufficient local seed weevil damage to satisfy their needs. The discordance between the distributions of seed weevil and *T. perfectus* is puzzling. The most plausible explanation is that *T. perfectus* females are actively searching for larval hosts that are not necessarily related to the distribution of adult weevils (Free & Williams, 1979). Since *Platygaster* (species A) attacks pod midge eggs, the positive relationship between parasitoids and adult midges is to be expected. It is even possible that parasitoids are attracted to the same chemical cues from plant damage that the midge uses to find oviposition sites (**Section 3.5**).

The distribution of insects on arable crops show both temporal and spatial variation. As insect distribution is rarely uniform, knowledge of spatial distribution is important for accurate sampling strategies for both pests and parasitoids. Subsequently, it may be possible to incorporate spatial information into pesticide spraying regimes.

4. EXAMINATION OF PEST MONITORING DATA

4.1 Introduction

Since 1981, stratified sampling of winter oilseed rape crops has been done, as part of the ADAS/CSL Pest Monitoring Scheme (PMS), to determine population levels of seed weevil in commercial crops in England & Wales. This section reports the results of an analysis of the accumulated database of pest and parasitoid numbers in commercial oilseed rape, developed from 1981 to 1994. This determines pest incidence and the potential for the successful control by parasitoids of damaging pest outbreaks.

4.2 Methods

In each year, from 51 to 81 crops of winter oilseed rape which had received no insecticide treatments against inflorescence pests, and which represented all popular modern cultivars, were sampled. The crops comprised a combined area of from 542 to 1,746 ha (0.2–1.0% of the total area grown). The number of crops sampled in each region of England & Wales was stratified according to the proportion of the national area grown. The 'regions' were: Eastern England, Midlands and West, Northern England, South East England, South West England, Wales. The counties included in each of these regions were standardised throughout the monitoring scheme. Fields to be sampled were selected from random stratified lists of farms known to grow oilseed rape, selection being completed before any farms were visited. Samples were taken at three growth stages: early to mid-flowering on the main raceme (GS 4.2–4.5); mid- to late flowering on the main raceme (GS 4.7–4.9); and between the end of flowering on the main raceme (GS 4.9) and the end of all flowering). At each visit, the tops of 20 plants from a transect across the field were beaten into a white tray and the number of adult seed weevils caught were recorded. Where pest populations required application of an insecticide to the sampled crop or where, for some other reason, an insecticide was to be applied, arrangements were made for an unsprayed area to be left for PMS use.

From 1988 to 1994, pod samples were taken from each field for assessment of seed weevil and pod midge larval infestations. At least 4 weeks after flowering, 20 plants (including 2 from the headland) were collected from along the transect (i.e. that used previously for monitoring adults). The main and 3rd-lowest secondary raceme were collected and returned to the laboratory where sub-samples of 10 pods were removed from both racemes of each plant (i.e. 20 pods per plant). Each pod was dissected under a low-powered microscope or a ×10 lens and the number of live, parasitised or dead seed weevil or pod midge larvae recorded.

Although these data were collected for other purposes, it was considered that a low-level analysis may be useful in assessing the current status of seed weevil and pod midge, and might also provide limited data on parasitoids. N.B. Pod dissections yielding data on the incidence of seed weevil larvae and their parasitoids were not included as part of the PMS protocol until 1988, and analysis under the present project has concentrated on the 5-year period 1990–1994 when the revised protocol had been tested and developed.

4.3 Results

4.3.1 *Seed weevil incidence*

The results of the stratified sampling programme done in winter oilseed rape from 1981 to 1994 indicated that numbers of seed weevil infesting the crop have fluctuated considerably during the last 13 years, reaching a peak in 1990 with a mean of 0.69 weevils per plant (**Table 4.1**). More recently, weevil infestations have been declining and, in 1994, they reached the lowest national mean recorded since sampling began. Differential seed weevil incidence between regions was analysed in each year and have been reported in the annual (unpublished) ADAS/CSL PMS reports.

Table 4.1 *Infestation levels of seed weevil in commercial winter oilseed rape crops, 1981–1994.*

Year	*No. fields sampled*	*Mean no. seed weevils/plant*	*% fields with >1 weevil/plant*	*% fields with >2 weevils/plant*	*% fields with >2.5 weevils/plant*
1981	51	0.23	2.0	0	0
1982	70	0.27	6.0	1.4	1.4
1983	76	0.48	12.0	0	0
1984	74	0.35	8.0	1.4	0
1985	65	0.65	27.4	4.6	1.5
1986	63	0.34	4.8	1.6	1.6
1987	52	0.33	9.6	0	0
1988	68	0.18	4.4	0	0
1989	68	0.46	16.2	4.4	4.4
1990	68	0.69	8.8	2.9	0
1991	81	0.48	11.1	2.5	0
1992	86	0.45	4.7	2.3	0
1993	67	0.20	4.5	0	0
1994	73	0.09	0	0	0

Until 1992, the economic treatment threshold for seed weevil on winter oilseed rape was set at 1 weevil per plant (Cooper & Lane, 1991). This threshold was raised to 2 weevils per plant in 1992 in response to the changes to the European Commission support scheme for the major oilseeds which was implemented under CAP reform (Lane & Walters, 1993). In relation to the old economic treatment threshold of 1 weevil per plant, up to a maximum of 27.4% of the fields surveyed in any individual year warranted treatment, a figure reached in 1985. However, 1985 was an extreme year and, if excluded, the percentage of fields warranting treatment on economic grounds varied from 0 in 1994 to 16.2% in 1989. On the basis of the 'new' threshold of 2 weevils per plant, no fields warranted spraying in 1981, 1983, 1987, 1988, 1993 or 1994, rising to a maximum of just 4.6% fields needing treatment in 1985. In very few of those fields that exceeded the 2 weevil per plant threshold did pest populations exceed 2.5 weevils per plant, representing over the 1981–1994 period, just six (0.62%) of the 962 fields sampled.

4.3.2 *Pesticide usage trend*

A comparison of insecticide usage survey data for 1988 and 1990 shows that the area of oilseed rape treated with an insecticide more than doubled in 1990 despite only a 12% increase in the area of crop grown (**Table 4.2**). This was largely accounted for by a significant increase in the use of pyrethroid insecticides. The area treated with insecticides in 1992 was 15% lower than in 1990, despite an 8% increase in crop area, with a 64% reduction in the weight of active ingredients used. In particular, there was a significant reduction in the use of triazophos (Davis *et al.*,1993).

Table 4.2 *Insecticide usage on oilseed rape in the UK, 1988–1992. Area of winter + spring rape grown: 347,000 ha (1988), 390,000 ha (1990), 420,000 ha (1992).*

Insecticide Group	*1988* *ha ('000)*	*t*	*1990* *ha ('000)*	*t*	*1992* *ha ('000)*	*t*
Organochlorine	22.0	11.4	19.2	8.4	7.1	2.4
Organophosphate	58.1	34.8	70.7	29.1	11.0	5.0
Carbamate	1.4	0.3	6.1	0.8	1.4	0.2
Pyrethroid	166.4	3.9	448.5	8.2	440.1	9.1
Total insecticide	256.1	50.6	546.2	46.5	462.9	16.7

The survey demonstrates that, when oilseed rape was highly profitable, overall insecticide usage (especially of the relatively low-cost pyrethroids), increased rapidly and remained at a high level. The use of the more expensive organophosphate compounds has generally declined.

An independent dataset obtained from the ADAS/CSL winter oilseed rape pest and disease survey (Hardwick *et al.*, 1993) has confirmed the more recent overall reduction in the insecticide applications made to oilseed rape (**Table 4.3**). However, against this trend, the proportion of crops treated during the flowering period in 1993 increased slightly. This was due largely to the often routine use of low-cost pyrethroid insecticides tank-mixed with, for example, fungicides that are commonly applied to control

Sclerotinia stem rot. On the evidence of pest monitoring surveys, it is likely that in the majority of cases, insecticide treatments were not justified. Moreover, the timing may not have been appropriate, even if insecticide sprays were needed. For example, during the spring/summer period of 1993 none of the fields monitored in the PMS exceeded the '2 adults per plant' economic treatment threshold for seed weevil, and only 4.5% exceeded the 'old' 1 weevil per plant threshold. In addition, applying the pollen beetle treatment threshold only 1.5% of the fields sampled warranted treatment and few if any should have been sprayed against cabbage aphid attack (K. F. A. Walters, unpublished). Despite this low apparent need, a total of 46% of fields received an insecticide spray during the spring/summer period in that year.

Table 4.3 *Insecticide usage on winter oilseed rape, 1988/89–1992/93.*

	% crops sprayed	
Growing season	*Autumn/winter*	*Spring/summer*
1988/89	4	19
1989/90	65	49
1990/91	86	53
1991/92	46	34
1992/93	24	46

The results of pest surveys indicate that seed weevil numbers rarely exceed the treatment threshold by a large margin; thus, if a sufficiently large population of parasitoids are present, techniques that result in a small increase in their beneficial effects may, in many fields, reduce the populations sufficiently to remove the economic justification for spraying. Further, the generally low incidence of seed weevils in most UK oilseed rape fields, accurate assessment techniques which are already available for practical use (Walters & Lane 1994a, b) and the positive beneficial effects of natural control agents (parasitoids) already present in their fields, should be used as arguments to reduce the degree of over-spraying which appears to be occurring.

4.3.3 *Parasitism of seed weevil larvae*

Analysis of the data showed that an encouraging level of parasitism of seed weevil larvae was recorded in all regions of the country, although a relatively low incidence of parasitised larvae were found in the first three of the 5 years investigated. In 1990, on average, almost 8% (± 15%) of the larvae were affected, with 4% (± 5%) parasitised in 1991 and 5% (± 7%) in 1992. The highest national mean percentages of parasitised larvae per field were recorded in 1993 and 1994 when 48% (± 31%) and 49% (± 22%) larvae were found, respectively. The high standard errors associated with these figures indicated the high variation of the level of parasitism between fields found within years. As a result of this variation no statistically significant (ANOVAR) differences were found between regions in the level of parasitism recorded in fields in any of the 5 years. The significant increase in percentage parasitism of larvae in commercial fields in 1993 coincided with the reduction in the use of triazophos (Hardwick *et al.*, 1993), found when pesticide usage trends were analysed (**Table 4.4**). Experiments carried out under this project have indicated that triazophos has a consistent detrimental effect on populations of *T. perfectus* (see **Section 2**). Samples to determine the level of parasitism in untreated plots in the same experiments have shown that parasitoid incidence is similar

Table 4.4 *Usage of triazophos on winter rape, as recorded in the ADAS/CSL Oilseed Rape survey, 1990-1994 (data raised to national levels).*

Year	*Area grown ('000 ha)*	*Area treated ('000 ha)*
1990	343.8	48.2
1991	387.8	72.7
1992	362.9	5.4
1993	314.8	2.1

to the levels found in the untreated fields of the PMS survey in 1993 and 1994. Thus, parasitism in commercial fields is currently at a level which might be manipulated to provide a useful level of control of the pest.

4.3.4 *Pod midge incidence*

Pod midge infestations were found in at least one field in every region in each of the first 3 years of the study (**Table 4.5**). In 1993 and 1994, they were present in every region except Wales but, in these 2 years, pod samples were dissected from only a very small number of fields in this area. All infestations were at very low levels and would not have warranted the application of insecticide treatments. No statistically significant (ANOVAR) differences in population levels were found between regions. Within regions, pod midge infestations were low but variable between fields in all years.

Table 4.5 *Infestation levels of pod midge in commercial winter oilseed rape crops, 1990–1994.*

Year	*No. of fields sampled*	*Mean number larvae/pod (range between regions)*	*% pods infested with larvae (range between regions)*
1990	77	0.03 (0.02–0.20)	1.11 (0.50–1.60)
1991	47	0.03 (0.003–0.07)	0.36 (0.09–0.63)
1992	46	0.19 (0.05–0.44)	0.92 (0.81–1.66)
1993	40	0.05 (0.00–0.09)	0.52 (0.00–0.91)
1994	40	0.07 (0.00–0.19)	0.50 (0.00–1.50)

4.3.5 *Parasitism of pod midge larvae*

No confirmed observations of parasitism of pod midge larvae within pods were recorded during the PMS. However, pods containing entirely, or almost entirely, dead pod midge larvae were frequently recorded, particularly in 1993 and 1994. The cause of death could not be ascertained from the data available.

4.4 Discussion

The large increases in the area sown to oilseed rape since the 1970s, and the attractive gross margins, has led to an increase in the perception of insect pest problems. However, pest monitoring surveys have consistently demonstrated that pest populations vary from year to year, and from field to field within the same season. More recent surveys have shown that infestations of the more important oilseed rape pests during the spring/summer period have been at low levels, with very few crops justifying insecticide treatment on a cost:benefit basis, even with the inexpensive pyrethroid products.

Recent changes in the oilseed rape management strategy, necessitated by the introduction of a new European Commission support scheme for oilseed rape under CAP reform, have resulted in the need to re-align inputs to lower returns (Askew, 1994). Crop production treatments currently account for 42% of the variable cost of winter oilseed rape production (Nix, 1994), insecticides accounting for 20% or less of this component. There is, however, potential for reducing certain insecticide inputs (Lane & Walters, 1994). For example, pyrethroid insecticides are relatively cheap and frequently used routinely either alone, or tank-mixed with a herbicide or fungicide by farmers, despite such routine treatments not being justified. The economic environment created by CAP reform results in a need to reduce such unnecessary pesticide applications to an absolute minimum. If this reduction is implemented, both the incidence of parasite populations in commercial crops and their importance as natural control agents will increase, thus reducing the risk that not spraying might result in pest damage. However, parasitoids will be most effective at reducing pest populations to sub-damaging levels if pest populations peak at or just above the damage thresholds. The records of population size in individual fields taken as part of PMS show that, in any one year, a maximum of only 4.6% of the field surveyed exceeded the new 2 weevils per plant threshold. In six of the 14 years in which records are available, none of the fields surveyed exceeded this threshold. Thus, very few fields appear to be at risk of serious pest damage resulting from seed weevil infestations. In addition, an extremely low proportion exceeded the 2.5 weevils per plant level (none in 10 of the 14 survey years). Thus, most of the fields which were at risk from pest damage exceeded the economic threshold by only a small margin; provided a sufficiently large population of parasitoids are present, techniques that result in a small increase in the effects of parasitoids may reduce the population sufficiently to remove entirely any economic justification for spraying. Following the overall reduction in insecticide use (particularly of the damaging triazophos), which has occurred since 1990, an increase in the level of parasitism has been noted, reaching almost 50% in 1993 and 1994. This indicates that parasitoid populations in unsprayed fields can reach levels which can exert effective control of seed weevil larvae.

The relatively low number of fields requiring treatment in most years, coupled with the observation that few exceeded economic threshold levels by more than a small margin, make further investigation of the incidence of seed weevil parasitoids, their potential as control agents and methods manipulating their numbers, worth pursuing. Further, since parasitised seed weevil larvae were found in commercial fields in all regions, and in all years in which observations were made, techniques to enhance levels of parasitism in such crops have potential throughout the rape-growing regions of England and Wales.

The incidence of pod midge was very low in all years for which the PMS records were available and no worthwhile data on pod midge parasitoids were obtained from the pod dissections. However, the absence of parasitised pod midge larvae within pods accords with other observations made during the course of this project, and with other studies, which have indicated that the major pod midge parasitoids are endoparasitoids and feed in fully grown larvae in the soil.

5. GENERAL DISCUSSION AND CONCLUSIONS

This study has identified *Trichomalus perfectus* as the most important parasitoid of seed weevil on winter rape in the UK, and confirmed the presence of this parasitoid in all the main rape-growing areas in England & Wales. It was encouraging to find that, at least in crops not treated with insecticide, the levels of parasitism by *T. perfectus* can be considerable, thus offering real potential for the future exploitation of this important parasitoid in bio-control on winter rape crops. Although the absence of records of parasitoids of pod midge during pod dissections (the basis of observations on the multi-site work and the pest monitoring surveys) was, at first, disappointing, this was subsequently explained by the discovery that all the species attacking pod midge (?*Aphanogmus abdominalis*, *Inostemma* sp., *Omphale clypealis* and *Platygaster* spp.) were endoparasites. They would not, therefore, be found by standard monitoring techniques.

Although this study has indicated that the organophosphate insecticide triazophos can significantly reduce the incidence of parasitism of seed weevil by *T. perfectus*, the effects of pyrethroid insecticides on parasitoids are less certain. In terms of parasitoid survival on winter rape, alphacypermethrin is clearly preferable to triazophos, particularly when applied at the 'normal' time (i.e. during flowering), which is before the main flight period of *T. perfectus*. However, it should not be assumed that the pyrethroids are entirely ‘safe’ to other beneficial organisms, including other useful parasitoids, such as those attacking pollen beetles (*Meligethes* spp.). Triazophos kills adult parasitoids and also parasitoid larvae within pods. This means that any control exerted by parasitoids such as *T. perfectus* is subsumed by the action of the insecticide and, on triazophos-sprayed crops, fewer parasitoids will survive to the next year. Alphacypermethrin applied during flowering kills adult seed weevils but not their eggs or larvae. Some of the weevils killed by the insecticide may already have laid eggs; late arrivals may also successfully deposit eggs on alphacypermethrin-treated crops. Any weevil larvae in the pods are then susceptible to attack by *T. perfectus* migrating into the crop after it is sprayed and, although reducing the numbers of available hosts (an indirect effect), the insecticide would normally have little direct effect on the parasitoids. A major difficulty in explaining effects, however, is the complex interaction of direct and indirect effects of pesticides on both parasitoids and their hosts, which are in turn compounded by host/parasitoid interactions.

It seems likely, from data produced during this study, that triazophos (which is applied at precisely the time that the female parasitoids are active within the crop) is a major cause of the decline in natural parasitism of seed weevil that has been observed over the past 15 years or so. It is also interesting that pest incidence survey data have indicated a recent and rapid increase in parasitism (viz. since 1992), which coincides precisely with a significant drop in the use of this particular pesticide on commercial crops. A clear message from this is that, to safeguard parasitoids such as *T. perfectus*, triazophos should not be used to combat seed weevil or pod midge on rape crops. The recent decline in the use this particular insecticide on oilseed rape, albeit for other reasons, is welcome and offers considerable hope that *T. perfectus* numbers could recover permanently, to the overall benefit of the oilseed rape growers, if farmers heed the advice offered as a result of this work.

It is encouraging to have discovered a 'new', relatively numerous, parasitoid of pod midge (namely *Platygaster* species A), and to have demonstrated that this parasitoid could be attracted within rape crops by using isothoicyanate-baited traps; the latter offers potential for the future development of a sophisticated monitoring system involving this parasitoid.

The failure to give a specific name to either of the two species of *Platygaster* found in this study, even though the few available identification keys were consulted and samples of adults were submitted to specialist taxonomists at recognised centres, highlights the current demise in research on insect taxonomy at the highest national, if not international, level. There is an urgent need for more taxonomists who could develop the necessary knowledge and expertise that is so vital for the full exploitation of these important insects in future bio-control or integrated crop management programmes.

The full implementation of a bio-control system for spring/summer pests of winter oilseed rape ideally requires consideration of the natural enemies (e.g. parasitoids) of pollen beetles, the only other summer pest of any potential consequence in the UK. Although pollen beetles are rarely of significance on winter rape, they can often be very numerous and some farmers are still tempted to spray against them, even though, as with seed weevil, economic thresholds for their control are rarely exceeded (Alford, *et al.*, 1991).

The presence on spring rape of *Omphale clypealis* as the main parasitoid enemy of pod midge, compared with *Platygaster* (species A) as the main parasitoid of pod midge on winter rape, emphasises the need for further studies of the parasitoid complex of pests on this crop, particularly as there are likely to be important interactions involving pests and parasitoids in areas where both spring and winter rape are grown. In this respect, no information is available on the possibly detrimental effect on parasitoids of insecticides applied to spring rape and the overall effect these might have in reducing parasitoid efficiency on either the winter or the spring crop.

Data from pest monitoring surveys (Section 4) indicate that, since 1981, only a small proportion of commercial crops in England & Wales have been at risk of economically significant damage from seed weevil and that, in those crops where treatments were economically justified, a high proportion exceeded the threshold by only a small margin. Thus, management approaches which allows slight improvement in the beneficial effects of natural enemies may be sufficient to avoid the need for spray applications in most, if not all, of these fields. There may also be value in introducing a parasitoid component into pest assessment systems, perhaps including specialist trapping techniques, that may call for the revision of current thresholds for spring/summer pests on winter rape.

Lowered prices for oilseed rape within the European Union have increased pressure on farmers to reduce agrochemical inputs, and the high level of unnecessary spraying in commercial crops indicates that significant economic savings could be made by applying current treatment thresholds and utilising natural control agents such as parasitoids. However, many UK farmers are worried about the consequences of leaving crops largely unsprayed against pests, disease and other problems (Alford *et al.*, 1995). The results of the present study should provide confidence to farmers that, in omitting insecticides against seed weevil and pod midge, they are not only saving the costs of treatment but also enhancing parasitoids. The latter can bring about added benefits, by themselves reducing pest levels and further reducing the likelihood that pests such as seed weevil might reach damaging levels. The parasitoid *T. perfectus* has a dual beneficial role, not only killing pest larvae that it parasitises but also killing those upon which the female parasitoids host-feed.

Oilseed rape is a unique arable crop in offering real potential for natural control of major pests by the manipulation of naturally occurring parasitoids. However, the industry will require clear guidance if low-input strategies for controlling pests such as seed weevil, in which *T. perfectus* is seen as a key component, are to become acceptable and viable commercially. It is believed that the results of this study will allow practitioners to advise with greater confidence on the benefits to be gained by following nationally advocated pest-control thresholds and strictly limiting applications of insecticides to those rare occasions when economic pest damage is a real possibility. The routine use of insecticides against pests such as seed weevil and pod midge on winter rape, in the mistaken belief that spraying will do no harm, has no place in a progressive, sustainable farming system.

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7. REFERENCES

ALFORD, D. V., COOPER, D. A. & WILLIAMS, I. H. (1991). *Insect pests of oilseed rape.* HGCA Oilseeds Research Revew No. OS1, 130 pp.

ALFORD, D. V., MURCHIE, A. K. & WILLIAMS, I. H. (1995). Observations on the impact of standard insecticide treatments on *Trichomalus perfectus*, a parasitoid of seed weevil on winter rape in the UK. *IOBC/WPRS Bulletin* **18:** (in press).

ASKEW, M. F. (1994). The impact of CAP reform on oilseed rape production at farm level. *Bulletin GCIRC* **10**: 206-210.

BARTLET, E., BLIGHT, M. M., HICK, A. J. & WILLIAMS, I. H. (1993). The responses of the cabbage seed weevil (*Ceutorhynchus assimilis*) to the odour of oilseed rape (*Brassica napus*) and to some volatile isothiocyanates. *Entomologia experimentalis et applicata* **68:** 295-302.

BLIGHT, M. M., HICK, A. J., PICKETT, J. A., SMART, L. E., WADHAMS, L. J. & WOODCOCK, C. M. (1995). Oilseed rape volatiles cueing host plant recognition by the seed weevil, *Ceutorhynchus assimilis*: chemical, electrophysiological and behavioural studies. *Proceedings IXth International Rapeseed Congress (Cambridge)* (in press).

BLIGHT, M. M., PICKETT, J. A., WADHAMS, L. J. & WOODCOCK, C. M. (1989). Antennal responses of *Ceutorhynchus assimilis* and *Psylliodes chrysocephala* to volatiles from oilseed rape. *Aspects of Applied Biology* **23:** 329-334.

BONNEMAISON, L. (1957). Le charançon des siliques (*Ceuthorrhynchus assimilis* Payk.). Biologie et méthodes de lutte. *Annales des Épiphyties* **8:** 387-543.

BÜCHI, R. (1993). Monitoring of parasitoids of the cabbage seed weevil *Ceutorhynchus assimilis* during 1990 and 1991 in Switzerland. *IOBC/WPRS Bulletin* **16:** 145-149.

COOPER, D. A. & LANE, A. (1991). Monitoring of oilseed rape pests in England and Wales. *IOBC/WPRS Bulletin* **14:** 5-13 .

DAVIS, R. P., THOMAS, M. R., GARTHWAITE, D. G. & BOWEN H. M. (1993). *Pesticides Usage Survey Report 108: Arable farm crops in Great Britain 1992.* London, MAFF. 89 pp.

DMOCH, J. (1975). Badania nad pasozytamichowacza podobnika (*Ceuthorrhynchus assimils* Payk.). I. Sklad gatunkowy i znaczenie ektopasozytow larwalnych. *Roczniki nauk Rolniczych, ser E* **5:** 99-112.

DMOCH, J. & KLIMEK, G. (1975). Badania nad paso ytami chowacza podobnika (*Ceuthorrynchus assimilis* Payk.). III. Obserwacje nad biologia *Trichomalus perfectus* (Walker). *Roczniki nauk Rolniczych E* **5:** 125-136.

DMOCH, J. & RUTKOWSKA-OSTROWSKA, Z. (1978). Host-finding and host-acceptance mechanism in *Trichomalus perfectus* Walker (Hymenoptera, Pteromalidae). *Bulletin de l'Academie Polonaise des Sciences, Série des sciences biologiques* **26:** 317-323.

EVANS, K. A. (1991). *The role of secondary plant metabolites in host-plant location by insect pests of oilseed rape* (Brassica napus *L.).* Unpublished PhD Thesis, Hatfield Polytechnic.

FLANDERS, S. E. (1953). Hymenopterous parasites of three species of oriental scale insects. *Bolletino del laboratorio di Zoologia Generale e Agaria "Filippo Silvestri" in Portici* **33:** 10-28.

FREE, J. B. & WILLIAMS, I. H. (1978). The responses of the pollen beetle, *Meligethes aeneus*, and the seed weevil, *Ceuthorhynchus assimilis*, to oilseed rape, *Brassica napus*, and other plants. *Journal of Applied Ecology* **15:** 761-774.

FREE, J. B. & WILLIAMS, I. H. (1979). The distribution of insect pests on crops of oilseed rape (*Brassica napus* L.) and the damage they cause. *Journal of Agricultural Science, Cambridge* **92:** 139-149.

GODAN, D. (1959). *Mymar autumnalis* (Först.) (*Anaphes autumnalis* Först.) (Chalcidoidea, Mymar.), ein bisher unbekannter Eiparasit des Kohlschotenrüsslers. *Nachrichtenblatt für den Deutschen Pflanzenschutzdienst, Stuttgart* **11:** 161-164.

HARDWICK, N. V., TURNER, J. A., WALTERS, K. F. A. & WRIGHT, D. M. 1993*). Winter oilseed rape pest and disease survey report.* CSL/ADAS.

ISIDORO, N. & BIN, F. (1988). Kairomone activity of *Dryomyia licthensteini* Fr. Lw. (Dipt.: Cecidomyiidae) sexual pheromone on the egg-larval parasitoid *Platygaster dryomyiae* Silv. (Hym.: Platygastridae). *Proceedings of the 15th Italian National Entomology Congress, L'Aquila, 13-17 June 1988*, pp. 939-944. [In Italian]

ISIDORO, N., WILLIAMS, I. H., SOLINAS, M. & MARTIN, A. (1992). Mating behaviour and identification of the female sex pheromone gland in the brassica pod midge (*Dasineura brassicae* Winn.: Cecidomyidae, Diptera). *Bolletino Istituto Entomologiia <G. Grandi> Universitas Bologna* **47:** 27-48.

JERVIS, M. A. & KIDD, N. A. C. (1986). Host-feeding strategies in hymenopteran parasitoids. *Biological Review, Cambridge* **61:** 395-434.

JOURDHEUIL, P., COUTIN, R. & LACOTE, J. P. (1974). Evolution du niveau des populations de *Ceuthorrhynchus assimilis* Payk. dans le Lauragais. *Information techniques CETIOM* **38:**11-13.

LABORIUS, A. (1972). Untersuchungen über die Parasitierung des Kohlschotenrüsslers (*Ceutorhynchus assimils* Payk.) der Kohlschotengallmücke (*Dasyneura brassicae* Winn.) in Schleswig-Holstein. *Zeitschrift für angewandte Entomologie* **72:** 14-31.

LANE, A. & WALTERS, K. F. A. (1993). Recent incidence of cost-effective control of pests of oilseed rape in England and Wales. *IOBC/WPRS Bulletin* **16:** 185-192.

LANE, A. & WALTERS, K. F. A. (1994). Pest control requirements of oilseed rape under reformed CAP. *Aspects of Applied Biology* **40:** 171-181.

LERIN, J. (1984). Effect de deux isothiocyanates sur les niveaux de capture en cuvettes jaunes d'insectes ravageurs du colza. *Acta Œcologica: Œcologia Applicata* **5:** 61-70.

LERIN, J. (1987). A short bibliographical review of *Trichomalus perfectus* Walker, a parasite of the seed pod weevil *Ceuthorrynchus assimilis* Payk.. *IOBC/WPRS Bulletin* **10:** 74-78.

McKENNA, D. (1972). *Study of the effects of insecticide management on the seedpod weevil (*Ceutorhynchus assimilis *Payk.) and its parasites*. Unpublished MSc Thesis, University of London.

MURCHIE, A. K. (1995). *Parasitoids of cabbage seed weevil and brassica pod midge in oilseed rape*. Unpublished PhD Thesis, Keele University.

NASRELDIN, N. (1973). *A study of the weevil complex on mustard with special reference to the seedpod weevil*. Unpublished PhD Thesis, University of London.

NILSSON, C. (1985). Impact of ploughing on emergence of pollen beetle parasitoids after hibernation. *Zeitschrift für angewandte Entomologie* **100:** 302-308.

NIX, J. (1994). *Farm Management Pocketbook.* 25th edition (1995). Wye College, University of London.

ROSEN, H. VON (1964). Untersuchungen über die Verbreitung und Biologie von zwei Pteromaliden in Rapsschoten (Hym., Chalcidoidea). *Statens växtskyddsanstalt Meddelanden* **12:** 451-465.

SMART, L. E., BLIGHT, M. M. & RYAN, J. (1995). Response of pollen beetles, *Meligethes* spp., to volatiles from *Brassica napus*. *Proceedings IXth International Rapeseed Congress (Cambridge)* (in press).

SYLVÉN, E. (1949). Skidgallmyggan, *Dasyneura brassicae* Winn.. *Statens Växtskyddanstalt Mededeling* **54:** 1-120.

SYLVESTER-BRADLEY, R. & MAKEPEACE, R. J. (1984). A code for stages of development in oilseed rape (*Brassica napus* L.). *Aspects of Applied Biology* **6:** 399-419.

WALTERS, K. F. A. & LANE, A. (1994a). *The development of an improved management strategy for cabbage seed weevil in oilseed rape.* In: *Individuals, Populations and Patterns in Ecology*, pp 187-197. Eds S. R. LEATHER, N. MILLS, A. D. WATT & K. F. A. WALTERS. Andover: Intercept Press.

WALTERS, K. F. A. & LANE, A. (1994b). Sampling procedures for pests of winter oilseed rape: meeting the needs of the crop consultant. *Aspects of Applied Biology* **37:** 83-94.

WHITEHEAD, R. [ed.] (1995). *UK Pesticide Guide*. CAB International & BCPC.

WILLIAMS, I. H. & MARTIN, A. P. (1986). Evidence for a female sex pheromone in the brassica pod midge *Dasineura brassicae*. *Physiological Entomology* **11:** 353-356.

WILLIAMS, I. H. & WALTON, M. (1990). A bibliography of the parasitoids of the brassica pod midge (*Dasineura brassicae* Winn.). *IOBC/WPRS Bulletin* **13:** 46-52.

APPENDIX I

Scientific publications produced during Project

1. Alford, D. V., Williams, I. H. & Murchie, A. (1993). Parasitoids of seed weevil and pod midge in winter oilseed rape. *13th Long Ashton International Symposium – Arable Ecosystems for the 21st Century, 14–16 September 1993*. [Abstract]

2. Murchie, A. K. (1994). Insect pest and parasitoid distribution in a field of oilseed rape (*Brassica napus* L.). *Norwegian Journal of Agricultural Sciences. Supplement* **16:** 409.

3. Alford, D. V., Murchie, A. K. & Williams, I. H. (1995). Observations on the impact of standard insecticide treatments on *Trichomalus perfectus*, a parasitoid of seed weevil on winter rape in the UK. *IOBC/WPRS Bulletin* **18:** (in press).

4. Alford, D. V., Emmett, B. J., Green, M. R., Murchie, A. K., Williams, I. H., Raw, K. A. & Walters, K. F. A. (1995). Field experiments to assess the status and importance of *Trichomalus perfectus*, a parasitoid of seed weevil on winter oilseed rape in the UK. *Proceedings IXth International Rapeseed Congress (Cambridge)* (in press).

5. Murchie, A. K. , Williams, I. H. & Smart, L. E. (1995). Responses of brassica pod midge (*Dasineura brassicae*) and its parasitoid (*Platygaster* sp.) to isothiocyanates. *Proceedings IXth International Rapeseed Congress (Cambridge)* (in press).

6. Murchie, A. K. (1995). *Parasitoids of cabbage seed weevil and brassica pod midge in oilseed rape*. Unpublished PhD thesis. Keele University.

APPENDIX II

Popular articles published or promotional material produced during Project

1. "*Parasites could provide pest control option.*" David Alford. **Arable Farming Plus, Vol. 21** (March 1994), pp. 16, 18–19.

2. "*The role of parasitoids.*" Ingrid Williams & Archie Murchie. **Agronomist** (Spring 95), pp. 13-15.

3. "*Using parasites to control seed weevil and pod midge on winter oilseed rape.*" Handout at **MAFF/LINK Technologies for Sustainable Farming Systems Collaborative Research Demonstration**, ADAS Boxworth – 24 June 1994.

4. "*Natural control of seed weevil on winter rape.*" In: **ADAS Research 1994/95**, p. 15 (1995).

5. "*Insecticides hold back predators.*" David Alford. **Oilseeds & Industrial Crops** (May 1995), p. 2.