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Sub-lethal effects of deltamethrin residues on the within-crop behaviour and distribution of *Coccinella septempunctata*

John A. Wiles & Paul C. Jepson
Ecotoxicology Research Group, Department of Biology, University of Southampton, Biomedical Sciences Building, Bassett Crescent East, Southampton SO9 3TU, UK

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Abstract

The behaviour and distribution of adult *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) were recorded in two plots of winter wheat infested with the cereal aphids *Sitobion avenae* (F.) and *Metopolophium dirhodum* (Walk.) (Homoptera: Aphididae). One plot was sprayed with the pyrethroid insecticide deltamethrin at a rate of 6.25 g a.i./ha and the other was left unsprayed. Single ladybird beetles were released sequentially on the ground at the centre of the sprayed and unsprayed plots and their behaviour and position in the crop canopy were recorded at 30 second intervals for a total of 15 min per beetle. Assessments, with fresh beetles, continued for four days after spray application with a total of eighty ladybird beetles observed. The 15 min period was selected to avoid lethal effects and no ladybird beetles were killed or knocked down as a result of exposure to deltamethrin residues during this period. Significant differences were found between the overall behaviour patterns of *C. septempunctata* in the untreated and deltamethrin treated plots up to three days after the spray application. Ladybird beetles exposed to deltamethrin residues were observed to walk and groom significantly more frequently and to rest significantly less frequently than those in the unsprayed plot. Significant differences were also found between the observed distribution of ladybird beetles in the sprayed and unsprayed crop canopies, with higher numbers of observations towards the bottom of the crop canopy and on the ground in the deltamethrin treated plot than in the untreated plot during the first two days after deltamethrin application. Upon the foliage itself, ladybird beetles were observed significantly more frequently on the abaxial leaf surface in the deltamethrin treated crop compared with the untreated crop. The results are discussed in terms of possible evidence for the repellency of deltamethrin to *C. septempunctata* and also the implications for integrated pest management of changes in predator behaviour and crop distribution resulting from sub-lethal uptake of insecticides.

Introduction

Coccinellid beetles are important arthropod predators of many aphid pests (Frazer, 1988). Within crops they will undertake a wide range of behaviours, including location of food, mates and oviposition sites and finding refugia to escape adverse conditions. These behaviours are mediated by diurnal activity patterns and sensory perception, internal factors, such as hunger and reproductive state (Dixon, 1959; Carter & Dixon, 1982; Rhamhalinghan, 1987) and external environmental factors, such as climatic conditions (Nakamuta, 1987), habitat quality (Honek, 1982, 1983; Carter & Dixon, 1982) and possibly exposure to pesticides.

If sub-lethal doses of pesticides are picked up by predators they may cause behavioural changes, such as altered foraging patterns, disrupted sexual communication or host recognition (Elzen, 1989), and/or physiological changes, such as altered reproduction, reduced longevity, egg viability or fitness (Moriarty, 1969). It is therefore important to understand these changes if we are to exploit biological control and the augmentation of natural enemies for pest management purposes.

Several authors have determined the toxicity of pesticides to coccinellid beetles in the laboratory (eg. Coats *et al.*, 1979; Tripathi *et al.*, 1988; Wiles & Jepson, 1992) and in the field (eg. Vickerman *et al.*, 1987; Poehling, 1988; Zoebelein, 1988; Wiles, 1992) but few have looked at the more subtle, sub-lethal influence that contact with pesticide residues may have upon their behaviour. Such sub-lethal effects are well documented for the pyrethroid insecticides and examples include the repellent/irritant responses shown by aphids (Highwood, 1979; Rice *et al.*, 1983; Lowery & Boiteau, 1988; Adams & Hall, 1990), mites (Iftner & Hall, 1983; Penman & Chapman, 1983; Berry *et al.*, 1990) and honeybees (Delabie *et al.*, 1985) and also antifeedant responses shown by Lepidoptera (Tan, 1981, 1982) and Coleoptera (Hajjar & Ford, 1990). Relatively little information is available however, concerning the possible sub-lethal effects of pyrethroids on predators in the field.

This paper describes a field study to investigate the possible sub-lethal effects of the pyrethroid insecticide deltamethrin on adult *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) exposed to spray residues in a mature winter wheat crop. The aims of the study were; 1) to determine if exposure to deltamethrin residues affected the foraging behaviour of *C. septempunctata* adults in a cereal crop; 2) to determine if exposure affected their distribution in the cereal crop canopy and 3) to determine if there was any evidence of repellency.

Materials and methods

Test invertebrates. Adult *C. septempunctata* were collected from unsprayed hedgerows and field verges on the Leckford Estates, near Stockbridge, Hampshire and on the South Allenford Farms, Damerham, Hampshire, UK with a hand-held aspirator in May and June 1991. After collection the beetles were kept in ventilated boxes in an insectary, maintained at 19–22 °C, 55–70% r.h. and a photoperiod of 16L:8D and were provided with barley plants infested with cereal aphids prior to the experiment. On each day of the experiment the boxes were removed from the insectary and taken to the field site. All of the ladybird beetles used in the study were provided with food 24 h prior to the experiments.

Test plots. These consisted of two 2 × 15 m areas of winter wheat, cv. Apollo, at decimal growth stage 69 to 71 (Zadoks *et al.*, 1974). The plots had a mean crop density of 412 tillers per square metre and contained natural infestations of the cereal aphids *Sitobion avenae* (F.) and *Metopolophium dirhodum* (Walk.) (Homoptera: Aphididae). Aphid numbers on the ears and flag leaves of twenty marked tillers within each plot were assessed prior to spray application and daily thereafter throughout the experimental period. One plot was sprayed with deltamethrin ('Decis' 25 g/litre EC, Hoechst), using an Oxford precision hand-held sprayer fitted with a dry boom with four Lurmark 02-F80 nozzles (BCPC Nozle Code F80/0.80/3) spaced 50 cm apart and operated at 2 bar pressure. The sprayer was calibrated to deliver spray at a rate equivalent to the recommended field rate of deltamethrin in U.K. cereals (i.e. 6.25 g a.i./ha in 200 l water). The other plot was left unsprayed to act as an untreated control. The treated plot was situated 20 m downwind of the untreated plot to avoid contamination by spray drift. Spray deposits in the treated plot were allowed to dry for approximately 30 minutes before the experimental introductions and observations began.

Observation procedure. Individual ladybird beetles were released onto the ground at the centre of the control or treated plot and observations began one minute later. The behaviour of each beetle and its' position in the crop canopy were recorded at 30 second intervals for a period of 15 min. The test ladybird was then removed from the plot and placed in a separate container. The relatively short 15 min. observation period was chosen because observations in treated and control areas could not be made concurrently. The ladybird beetles were therefore released alternately in the control and treatment plots and the short observation period enabled higher numbers of beetles to be observed. New individuals were used in each test. In addition, preliminary studies had shown that knockdown, resulting from pesticide uptake, was unlikely to occur during the 15 min observation period. The 30 second recording interval was chosen because continuous recording of behaviour changes was difficult within the crop canopy.

A total of 80 ladybird beetles were used in the experiment, eight were released in the control plot and eight in the treated plot each day. Observations continued for four days after the deltamethrin treated plot had been sprayed. All observations took place between 10-00 and 16-00 BST (British Summer Time). Maximum temperatures were recorded in the plots on each day.

Behaviour categories. Four behavioural categories were chosen for the experiment from preliminary behavioural observations of adult *C. septempunctata*. These were defined as:

1) Walking - any ambulatory movement.
2) Resting - remaining motionless with no visible movement of body parts.
3) Feeding - handling or consumption of prey items.
4) Grooming - rubbing motions of the legs over the body, elytra and wings.

Flying was recorded in four of the 80 individuals observed. Observations were terminated if the ladybird beetle flew out of the experimental area.

Crop canopy distribution. Observations of ladybird beetle position in the cereal crop were classified into six crop strata. These were the ear, flag leaf, stem (from ear to ground level), first leaf, second leaf and ground. The observations on the leaves were further divided into adaxial and abaxial leaf surfaces. These canopy distribution categories were chosen because pesticide residues and their effects on non-target invertebrates are known to partition out between these crop strata (i.e. Unal & Jepson, 1991; Cilgi & Jepson, 1992).

Statistical analyses. Behaviour category data and crop distribution data for ladybird beetles in the control and treated plots were compared on each day of the experiment by contingency χ^2 analysis using Yates' correction where df=1 (Cohen, 1988). Behavioural transition probabilities, which describe the likelihood of beetles changing from one behaviour to another after each 30 second period, were estimated using purpose written in-house computer software (D.W. Salt, Portsmouth University) assuming a first order, four state Markov chain.

Results

Behaviour of C. septempunctata *in the cereal crop canopy.* No ladybird beetles were knocked down during the period of observation in the deltamethrin treated plot. Four beetles, however, exhibited flight behaviour and flew out of the experimental plot during the observation period. These were therefore excluded from the analysis. All four of these ladybird beetles flew out of the deltamethrin treated plot, two flying on the day of spray application and the other two flying on the third day after spray application.

The proportion of observations of ladybird beetles that fell into each of the four behaviour categories in the treated and untreated plots over the five days of assessment are given in Fig. 1. Observations of *C. septempunctata* walking behaviour during the five days accounted for between 36 and 82% of the observations in the deltamethrin treated plot and between 14 and 58% of the observations in the untreated plot. Resting behaviour accounted for between 12 and 60% of the observations in the treated plot and 38 and 85% in the untreated plot, whereas feeding and grooming behaviour accounted for between 0 and 3% and 1 and 5% of the observations respectively in the treated plot and between 1 and 7% and 1 and 3% in the untreated plot.

Contingency χ^2 analysis of observational count data indicated significant differences in the overall behaviour patterns of the ladybird beetles between the untreated and treated plots on Day 1 (χ^2=48.0; df=3; P<0.001), Day 2 (χ^2=33 9; df=3; P<0.001), Day 3 (χ^2=48.7; df=3; P<0.001) and Day 4 (χ^2=10.7; df=3; P<0.05). There were however, no significant differences in the overall patterns of ladybird beetle behaviour in the untreated and treated plots on Day 5 (χ^2=0.7; df=3; P>0.05). Comparisons between individual behaviours (Table 1) indicated that ladybird beetles in the treated plot were observed to walk significantly more frequently and to rest significantly less frequently than those in the untreated plot on Days 1, 2 and 3. Ladybird beetles in the treated plot were also observed to groom significantly more frequently than those in the untreated plot on Day 1 and to feed less than those in the untreated plot on Days 1 to 4. These differences were also indicated in the behavioural transition probabilities given in Table 2. On the first two days, the ladybird beetles showed a higher probability of walking during consecutive observations in the deltamethrin treated plot than in the untreated plot. The ladybird beetles also showed a higher probability of walking preceding grooming or vice versa in the treated plot than in the untreated plot on all five days. Example behaviour sequences for individual ladybird beetles in the treated and untreated plots are given in Fig. 2.

The sensitivity of the 30 second observation period for detecting differences in behaviour was estimated by calculating the mean consecutive time spent in each behaviour by beetles in the treated and untreated plots for each day of the experiment (Table 3).

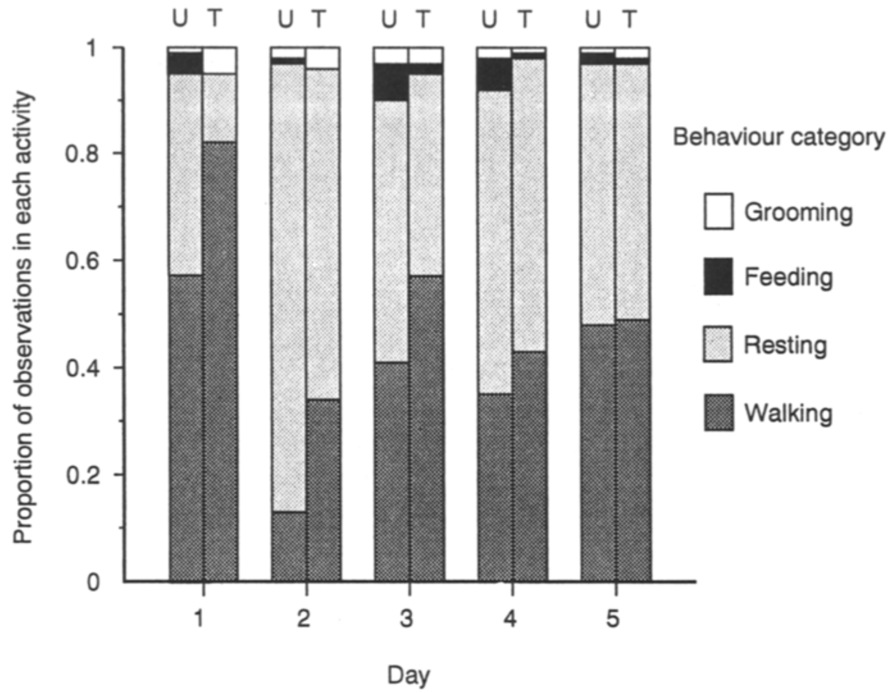

Fig. 1. Proportions of observations of *C. septempunctata* adults in each behaviour category in the untreated (U) and deltamethrin treated (T) wheat plots during the five day experimental period. Day 1=day of spray application, Day 2=first day after spray application, Day 3=second day after spray application, Day 4=third day after spray application, Day 5=fourth day after spray application.

Table 1. χ^2 statistics comparing numbers of observations within each behaviour category on each day for *C. septempunctata* in the deltamethrin treated and untreated wheat plots. –=Test could not be performed; df=1;***=P<0.001;**=P<0.01;*–P<0.05; ns=not significant, P>0.05. See Fig. 1. for directions of differences

Behaviour category	Day of experiment				
	Day 1	Day 2	Day 3	Day 4	Day 5
Walking	30.1***	30.1***	11.1***	3.2ns	0.1ns
Resting	33.1***	30.8***	5.4*	0.2ns	0.1ns
Feeding	–	–	5.3ns	8.4**	0.3ns
Grooming	6.9**	1.8ns	0.1ns	0.8ns	0.6ns

The results indicated that the 30 second period may have been adequate for detecting differences in walking and resting behaviour because the mean times spent in these behaviours were greater than the assessment period. The 30 second assessment period was however less sensitive to detecting differences in feeding and grooming behaviours. The values in Table 3 indicated that consecutive observations in these behaviours were rare, as the mean times were equal to 30 seconds. Therefore, the frequency of occurrence of these behaviours may have been under-estimated. However, relative differences are still likely to be indicative of changes in behaviour patterns.

Table 2. Behavioural transition probabilities for *C. septempunctata* adults in untreated and deltamethrin treated wheat plots during the five days of assessment. Behaviour categories; w = walking, r = resting, f = feeding, g = grooming. Probabilities describe the likelihood of beetles changing from one behaviour to another after each 30 second period

Control plot					Deltamethrin treated plot				
		Day 1					Day 1		
From/To	w	r	f	g	From/To	w	r	f	g
w	0.703	0.256	0.042	0.000	w	0.826	0.138	0.000	0.037
r	0.345	0.643	0.012	0.000	r	0.680	0.160	0.000	0.160
f	0.111	0.222	0.333	0.222	f	0.000	0.000	0.000	0.000
g	0.000	1.000	0.000	0.000	g	0.800	0.200	0.000	0.000
		Day 2					Day 2		
From/To	w	r	f	g	From/To	w	r	f	g
w	0.556	0.444	0.000	0.000	w	0.625	0.346	0.000	0.029
r	0.124	0.840	0.000	0.036	r	0.200	0.753	0.000	0.047
f	0.000	1.000	0.000	0.000	f	0.000	0.000	0.000	0.000
g	0.167	0.833	0.000	0.000	g	0.429	0.571	0.000	0.000
		Day 3					Day 3		
From/To	w	r	f	g	From/To	w	r	f	g
w	0.750	0.185	0.065	0.000	w	0.708	0.232	0.036	0.024
r	0.205	0.741	0.045	0.009	r	0.333	0.655	0.011	0.000
f	0.176	0.353	0.235	0.235	f	0.250	0.000	0.000	0.750
g	0.000	0.800	0.200	0.000	g	0.666	0.333	0.000	0.000
		Day 4					Day 4		
From/To	w	r	f	g	From/To	w	r	f	g
w	0.566	0.374	0.051	0.010	w	0.598	0.374	0.009	0.017
r	0.322	0.617	0.061	0.000	r	0.277	0.708	0.015	0.000
f	0.267	0.333	0.200	0.200	f	0.333	0.666	0.000	0.000
g	0.250	0.750	0.000	0.000	g	1.000	0.000	0.000	0.000
		Day 5					Day 5		
From/To	w	r	f	g	From/To	w	r	f	g
w	0.586	0.397	0.017	0.000	w	0.612	0.320	0.017	0.051
r	0.407	0.537	0.056	0.000	r	0.294	0.667	0.039	0.000
f	0.250	0.250	0.000	0.500	f	0.333	0.333	0.000	0.333
g	0.666	0.333	0.000	0.000	g	0.800	0.200	0.000	0.000

Overall differences in the level of activity between days may be partly attributable to variations in environmental conditions such as temperature and/or light intensity. During the experiment the ladybird beetles were observed walking less frequently in the untreated plot on the days when the temperatures were lowest (Fig. 3). Food availability may also have influenced ladybird beetle behaviour. Aphid numbers in

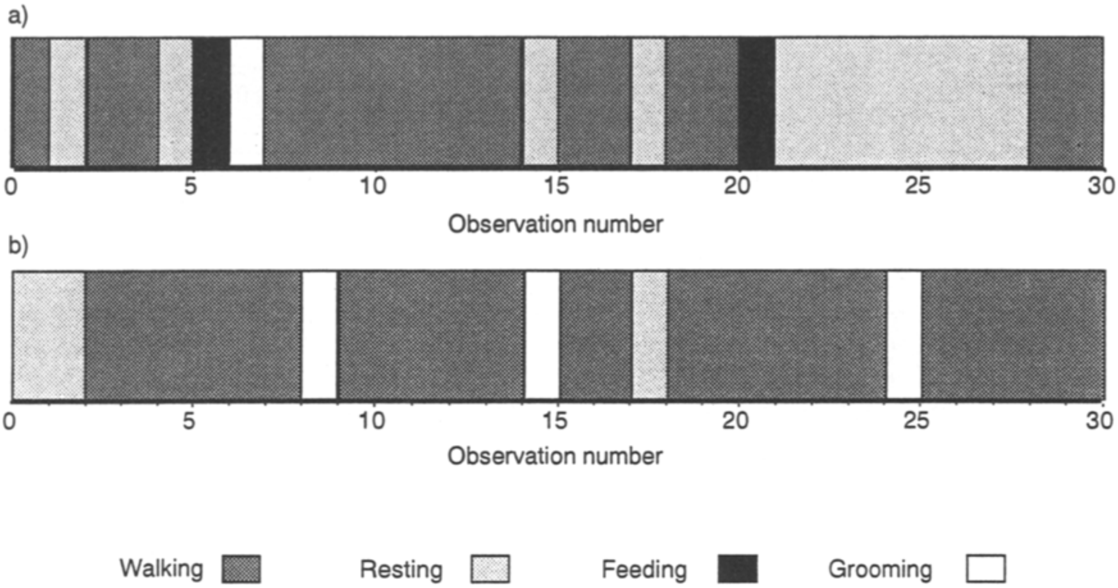

Fig. 2. Example behavioural sequences for a) a ladybird beetle in the untreated plot and b) a ladybird beetle in the deltamethrin treated plot on the first day of the experiment.

Table 3. Estimated consecutive time spent in each behaviour by *C. septempunctata* in a) untreated and b) deltamethrin treated wheat plots during the experiment. –=Behaviour not observed, 30*= no consecutive observations occurred

a)

Behaviour category	Estimated mean consecutive time spent in each behaviour(s)				
	Day 1 Mean±95% C.L.	Day 2 Mean±95% C.L.	Day 3 Mean±95% C.L.	Day 4 Mean±95% C.L.	Day 5 Mean±95% C.L.
Walking	112.2±24.0	66.3±21.6	105.0±25.8	76.5±17.4	73.2±16.8
Resting	85.2±45.6	159.9±79.8	101.4±31.2	78.9±15.0	76.5±15.9
Feeding	33.3±7.5	30*	31.8±3.9	30*	30*
Grooming	–	30*	35.9±12.9	30*	30*

b)

Behaviour category	Estimated mean consecutive time spent in each behaviour(s)				
	Day 1 Mean±95% C.L.	Day 2 Mean±95% C.L.	Day 3 Mean±95% C.L.	Day 4 Mean±95% C.L.	Day 5 Mean±95% C.L.
Walking	147.2±38.1	68.4±19.1	79.2±20.1	85.8±22.0	86.4±21.4
Resting	36.0±6.3	126.9±41.0	81.4±27.1	107.4±36.3	83.4±13.5
Feeding	–	–	30*	30*	30*
Grooming	30*	30*	30*	30*	30*

the deltamethrin treated plot declined from a mean of 16 aphids/ear to 1.2 aphids/ear and from 5.5 aphids/flag leaf to 0.7 aphids/flag leaf after spraying and the numbers remained low for the duration of the experimental period (Fig. 4). This compares with densities of approximately 14 aphids/ear and 6 aphids/flag leaf at the onset in the control plot which remained reasonably constant throughout the experimental period. Behaviour category data (Fig. 1) indicated that no feeding was observed for beetles in the treated plot on the first two days of the experiment, however some feeding was observed in the final three days. Feeding was observed on each day for beetles in the control plot.

Distribution of C. septempunctata *in the cereal crop canopy. C. septempunctata* distributions in the untreated plot were similar on all five days of the experiment, with a higher proportion of observations on the ear and flag leaves than on the stem, first and second leaves and ground (Fig. 5). Contingency χ^2 analysis to compare the overall numbers of ladybird beetle observations on the crop strata between the deltamethrin treated plot and the control plot within each day indicated significant differences in observed ladybird distributions on Day 1 (χ^2=14.5; df=5; P<0.05) and Day 2 (χ^2=55.6; df=5; P<0.001). No overall differences in ladybird distributions were found on Day 3 (χ^2=6.1; df=5; P>0.05), Day 4 (χ^2=6.3; df=5; P>0.05) or Day 5 (χ^2=3.4; df=5; P>0.05). Trends between the observed ladybird beetle crop distributions on the first two days of the experiment indicated that fewer observations occurred on the ears and flag leaves in the deltamethrin treated plot compared with the untreated plot. Also a higher number of observations of ladybird beetles were evident on the first leaves and on the ground in the deltamethrin treated plot than the control plot.

The proportion of observations on the flag and first leaf adaxial surfaces were lower in the treated plot than the untreated plot on the first three days of the experiment, varying between 48 and 68% and 61 and 86% respectively (Fig. 6). These distribution trends were investigated further by comparing total numbers of ladybird observations using contingency χ^2 analysis. Second leaf data were not included because of low numbers of observations on this crop stratum and because these leaves were desiccated. Significant differences were found between the proportions of ladybird observations on the abaxial leaf surfaces in the treated plot compared to the control plot on Day 1 (χ^2=19.2; df=3; P<0.001), Day 2 (χ^2=29.6; df=3; P<0.001) and Day 3 (χ^2=13.4; df=3; P<0.01), however no significant differences were found on Day 4 (χ^2=1.9; df=3; P>0.05) or Day 5 (χ^2=5.3; df=3; P>0.05). This indicated that ladybird beetles occurred more frequently on the adaxial leaf surface in the untreated plot on the first three days of the experiment compared with the ladybirds in the deltamethrin treated plot.

Discussion

The effect of deltamethrin on the behaviour of C. septempunctata. Significant differences in overall behaviour patterns were evident between ladybird beetles in the untreated and deltamethrin treated plots on the day of spray application and on the following three days. Trends between individual behaviours indicated significant increases in walking and grooming behaviour and significant decreases in resting and feeding behaviour for ladybird beetles in the deltamethrin treated plot compared with those in the untreated plot. This may indicate a sub-lethal irritant effect or hyperactivity caused by deltamethrin uptake. The higher proportion of observations of walking behaviour in the treated plot may also have been a result of increased searching for food which is known to be dependent upon hunger level in coccinellid beetles (Dixon, 1959; Carter & Dixon, 1982). All of the ladybird beetles used in these experiments were provided with food in the 24 h prior to observations in order to reduce this effect. However, it's importance during the 15 minute observation period could not be determined.

The behavioural transition probabilities confirmed that ladybird beetles in the deltamethrin treated plot had a higher probability of walking continuously or of walking and then grooming or vice versa than ladybird beetles in the untreated plot. Grooming behaviour is a reflex action (Eisner, 1961) and is probably initiated by an irritant on chemoreceptors located on the insect body. Grooming behaviour is shown during pyrethroid poisoning in house flies (Golenda & Forgash, 1986) and therefore increased grooming behaviour by the ladybird beetles in the treated plot is likely to have been a symptom of pesticide uptake. Grooming may also be an important route of contamination by insecticide residues as the ladybird beetle may transfer pesticide from its' appendages to its' body surfaces and even mouthparts. Behavioural changes induced by pesticide uptake are known to greatly affect the chance of an organism encountering further insecticide or the amount of pesticide that is picked up (Jepson *et al.*,

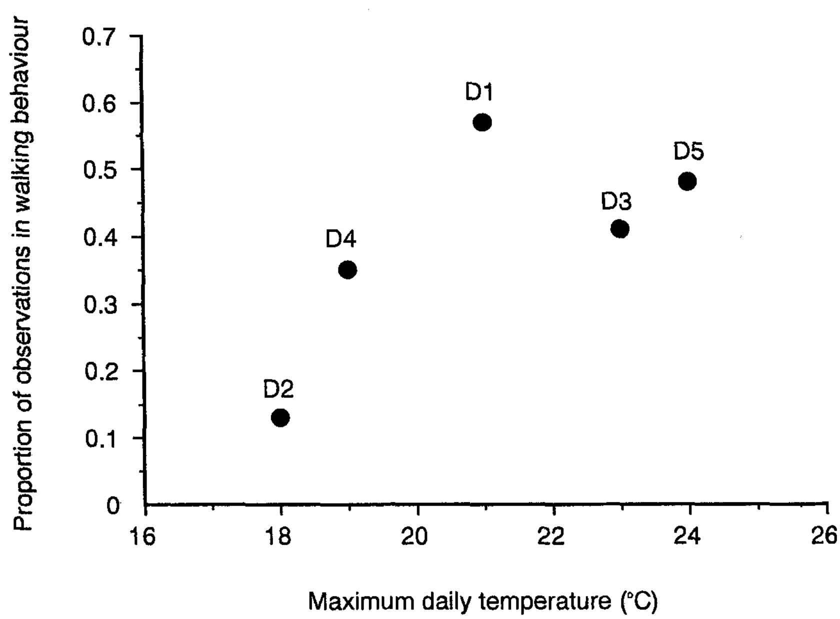

Fig. 3. Maximum daily temperatures in the wheat crop canopy during the experiment D1=day of spray application, D2=first day after spray application, D3=second day after spray application, D4=third day after spray application, D5=fourth day after spray application.

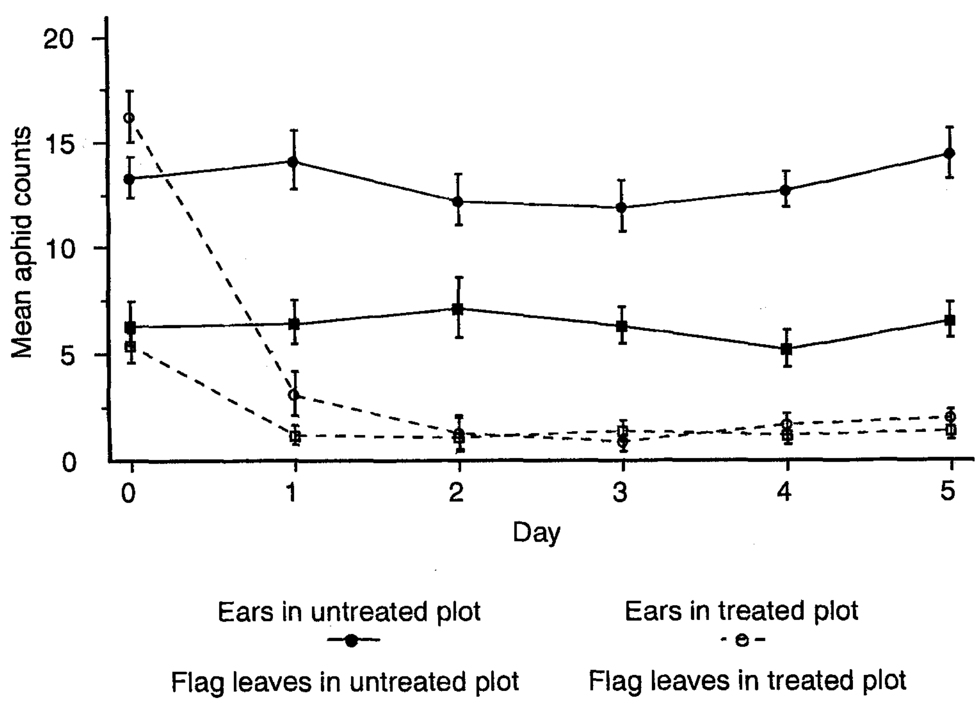

Fig. 4. Mean cereal aphid numbers on ears and flag leaves in the untreated and deltamethrin treated plots. Error bars indicate 95% confidence intervals.

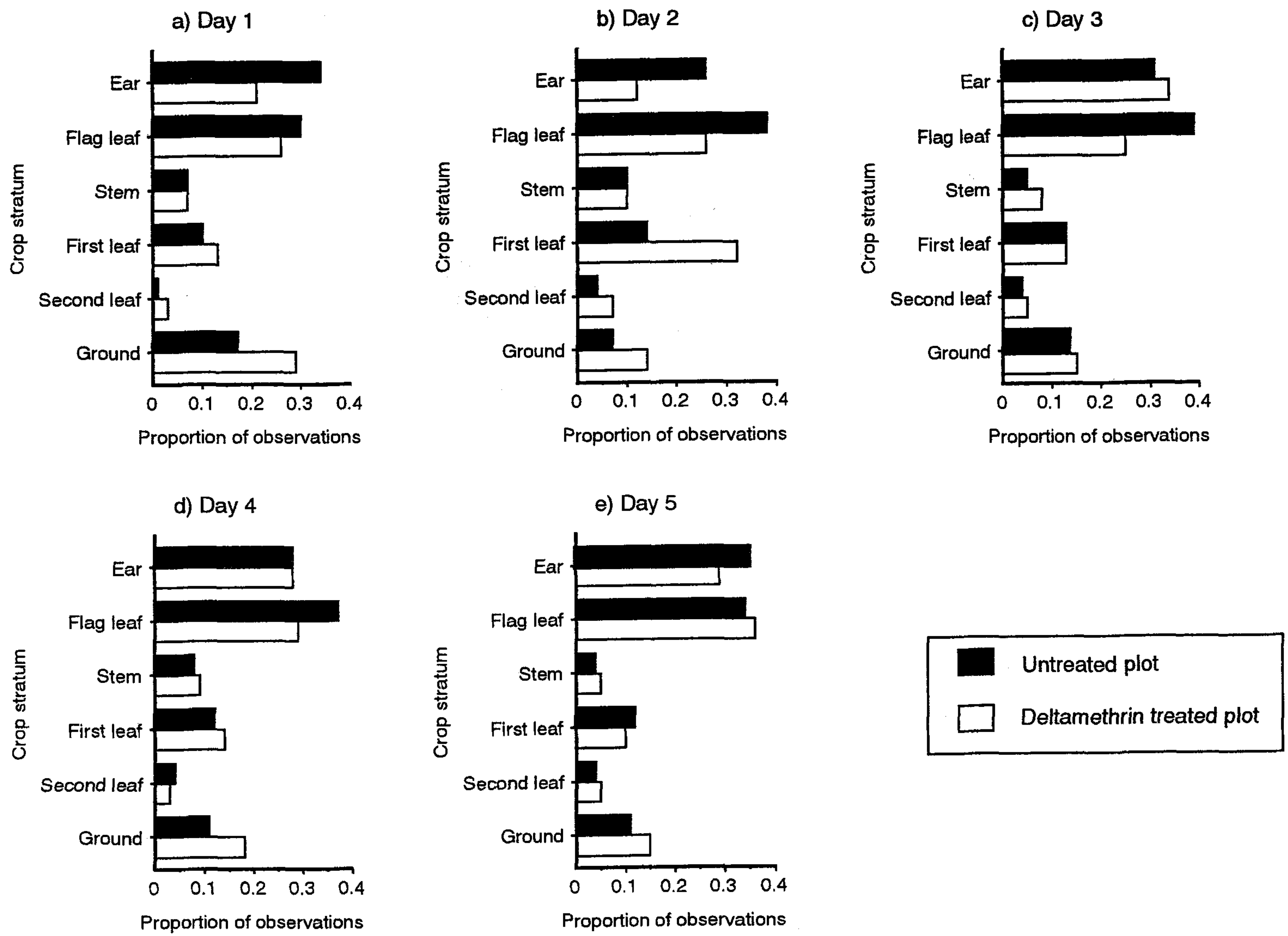

Fig. 5. Proportions of observations of *C. septempunctata* on each crop stratum in the untreated and deltamethrin treated wheat plots on the day of treatment and the following four days.

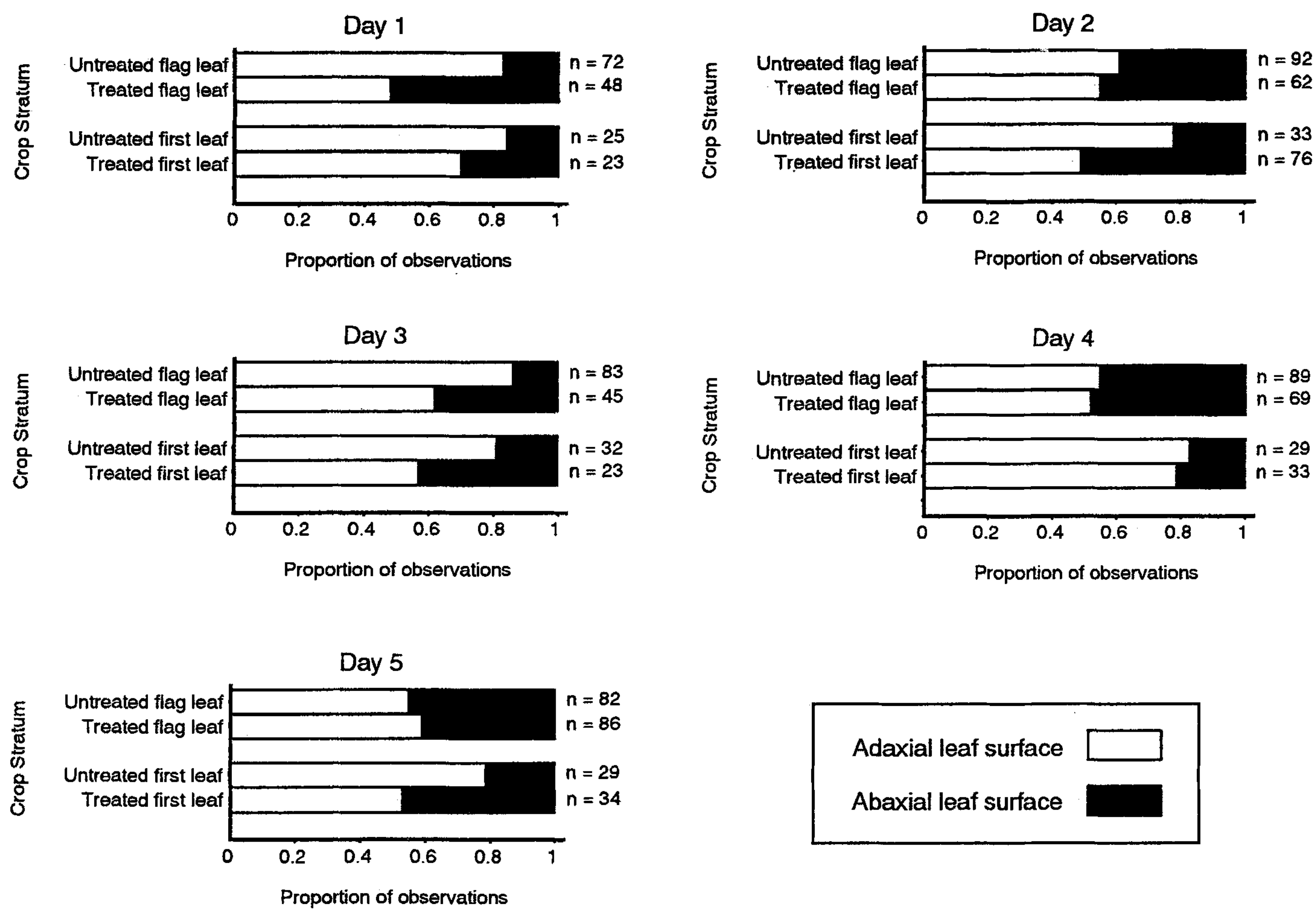

Fig. 6. Proportions of observations of *C. septempunctata* on adaxial and abaxial flag and first leaf surfaces in the untreated and deltamethrin treated plots during the experimental period.

1990). Therefore, by quantifying these changes using transition probabilities it may be possible to incorporate behavioural effects into models (e.g. Salt & Ford, 1984) to predict pesticide uptake and the possible impact of spray deposits on predators.

Less feeding was observed in the treated plot than in the control plot. This may have been a result of reduced prey availability and/or reduced stimuli from aphid honeydew in the treated plot. However, there may also have been more subtle interactions between sub-lethal poisoning effects on the ladybird beetles and feeding. For example, in dietary exposure experiments Wiles & Jepson (1993) have shown that aphid consumption by the carabid beetle *Nebria brevicollis* F. (Coleoptera: Carabidae) may be reduced significantly for several days after sub-lethal poisoning by deltamethrin. Decreased feeding after sub-lethal exposure to pesticides has also been shown in coleopteran predators by Dempster (1968) and Brust *et al.* (1986).

The effect of deltamethrin on the distribution of C. septempunctata *in a cereal crop canopy.* Coccinellid beetles are positively phototactic and negatively geotactic and are therefore often found at the apex of plants (Majerus & Kearns, 1989). The plant apex also tends to be the growing point of the plants where their prey, such as aphids, often feed. This may explain why the ladybird beetles were observed more frequently on the ears and flag leaves than lower in the crop canopy in the untreated plot during the experiment. The significant differences in ladybird beetle crop distribution between the deltamethrin treated plot and the control plot on the first two days of the experiment suggested that exposure to deltamethrin residues may cause a redistribution of ladybird beetles down the crop canopy towards the ground. This redistribution may have been mediated by the increased walking behaviour shown on these days which may have been caused by the sub-lethal poisoning effects of deltamethrin and/or decreased food availability in the treated plot.

Evidence for repellency of deltamethrin to C. septempunctata. Fewer ladybirds were observed on the adaxial leaf surface than on the abaxial surface in the deltamethrin treated plot for the first three days after spray application. This may indicate that deltamethrin had a repellent effect on the ladybird beetles because spray deposits are known to be lower on the abaxial plant surface than the adaxial surface (Cilgi & Jepson, 1992). This effect may also have been caused by increased walking activity in the treated plot resulting from hunger. However all ladybirds were provided with food before the experiment, in order to reduce hunger effects, and the alterations in behaviour were reduced by the third and fourth days after spray application despite the fact that aphids numbers were still low in the treated plot. This may indicate that deltamethrin causes a short-term irritant/repellent effect. Therefore, even though the effects of hunger should not be dismissed from the results, the higher numbers of observations of *C. septempunctata* on the abaxial leaf surface in the treated plot, together with the downward redistribution of the ladybirds in the crop canopy and the fact that all four ladybirds that flew out of the experimental plot during observation were in the treated plot, may provide some evidence to suggest that a deltamethrin spray may have a short-term repellent effect on *C. septempunctata*.

Implications for integrated pest management. Both the redistribution of ladybird beetles in the crop canopy and the possible repellent effects shown in this study may be important in determining the impact of deltamethrin on *C. septempunctata* in the 'real world'. *In situ* bioassays, with deltamethrin sprayed at a recommended field rate (6.25 g a.i./ha), have shown that high levels of mortality occur when adult *C. septempunctata* are exposed to residues on treated flag leaves (Unal & Jepson, 1991; Wiles, 1992). The movement of unconfined ladybird beetles, therefore, towards the bottom of the cereal crop canopy may reduce the degree of exposure of *C. septempunctata* to deltamethrin because spray residue levels will decline towards ground level (Cilgi & Jepson, 1992). In addition, the toxicity of deltamethrin is lower on soil compared with foliage because of reduced bioavailability (Unal & Jepson, 1991; Wiles, 1992). Both of these factors will therefore reduce the impact of deltamethrin on *C. septempunctata* populations in the crop after spraying.

The overall implications of these effects for the contribution of *C. septempunctata* to aphid pest suppression in cereals remain unclear. In this study the ladybird beetles showed reduced-feeding in the deltamethrin treated plot and moved away from the crop strata that the aphid pests inhabit. This may provide a short-term 'predator free window' during which the pest could possibly resurge. The duration of this effect was however trivial in terms of the time scale for aphid population growth and it is arguable that the benefits in terms of increased predator survival will outweigh the costs of reduced predation rate.

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