4 INSECTICIDE DRIFT FROM GROUND CROP SPRAYERS

B N K Davis, K H Lakhani, A J Frost, T J Yates & R Plant

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4.1 INTRODUCTION

There have been many studies on spray drift using tracer dyes collected on flat plates, tapes, nylon lines or other receptors. However, they do not give direct information on the biological impact of drift. In the case of insecticides, such effects are not readily observed but two approaches are possible. Short range and generally short-term effects can be recorded in natural populations or communities of non-target organisms in habitats adjacent to sprayed crops (Dobson, 1986; Williams *et al.*, 1987). This can be useful for distinguishing relatively sensitive and insensitive groups for different spray materials. However, bioassay experiments are more appropriate for measuring the width of buffer zones to protect beneficial insects and wildlife. Here, organisms are exposed in a controlled manner during pest control spraying.

Davis *et al.* (1991) described a bioassay technique for evaluating the effects of wind speed on insecticide spray drift from a tractor-powered hydraulic sprayer. In order to examine the influence of this one variable other factors were maintained as uniform as possible. Thus, site and operating conditions were controlled by using a field of short grass, by orienting the sprayed swathes at right angles to the prevailing wind on each occasion, by setting out targets - also in short grass - in line with the wind, and by using the same compound at the same rate for each trial.

This section describes bioassay measurements of drift made in agricultural crops during spraying by farmers. The objectives were (1) to see whether the techniques previously developed for controlled experiments could be used under typical agricultural conditions; (2) to relate drift deposition and its effects to physical features downwind of sprayed crops; (3) to compare results with those obtained under standardized experimental conditions at Monks Wood in 1988 and 1989; and (4) to estimate the sizes of buffer zones that would protect species outside the sprayed crop.

4.2 METHODS

4.2.1 Field and laboratory methods

Two insecticides were selected for these tests, cypermethrin and triazophos which are used against a wide spectrum of pests including Lepidoptera. The ground crops were peas and brussels sprouts which are sprayed for control of pea-moth *Cydia nigricana* (Fab.) and cabbage white *Pieris* spp. caterpillars. Topical dosing experiments on *P. brassicae* L. were first carried out to obtain LD_{50} values for cypermethrin and triazophos, and to compare these with the range of toxicity values already obtained for eight other compounds (Sinha, Lakhani & Davis, 1990). In the case of triazophos, 2-, 3- and 4-day-old larvae were compared simultaneously to determine the effect of age on sensitivity. An experimental drift trial with cypermethrin was also done at Monks Wood, using larvae of three different ages in case older larvae had to be used for field bioassays because of delayed spraying.

Four farms were selected in Cambridgeshire and Bedfordshire. Six to seven days notice of spraying was needed to have 2-day-old *Pieris brassicae* larvae ready on the day of spraying, but on the first occasion at Haverhill insufficient notice was given and the larvae were only one day old.

Bioassay targets were prepared essentially in the way described by Davis *et al.* (1991). To optimize the initial feeding of larvae, egg batches were placed directly on horse-radish plants (*Armoracia rusticana*), and kept in shaded, humid conditions at about 20°C. The day after hatching, the larvae were transferred to freshly cut leaves selected and trimmed to be as similar as possible. These leaves were stuck in flower arrangers' foam ('Oasis') in plastic pots flooded with water. On the following day they were transported to the test site (30 to 80 km).

The targets were set out in two to four replicate lines about 10 m apart, perpendicular to the downwind field edge at varying measured distances up to 25 m. Wind speed and direction were recorded on a chart anemometer (Vectair R500). When the direction was clearly oblique to the target lines at an angle θ, the measured distance d was adjusted to the effective distance d sec θ. The pots were placed on the ground at field edges, on road verges and in low crops, but at Haverhill where there was a tall crop of field beans on the downwind side the pots were suspended from collapsible wooden tripods so that the insects were just above crop height.

After spraying, the larvae were placed in Petri dishes on sections of sprayed leaf, transported back and kept in an incubator at 24°C. Mortality was assessed over three days.

A water-sensitive paper was pinned out next to each target leaf. Although "inefficient" as collectors of fine droplets, they provided a visual indication of drift deposition which was measured on an I^2S image processing system as described by Sinha, Lakhani & Davis (1990). An attempt was made at Haverhill to measure the cypermethrin drift directly by using "efficient" aluminium mesh cylinders ('Isopon' - 10 cm circumference x 6 cm long) suspended next to the target leaves. These were washed in 10 ml hexane which was injected onto a Varian Model 3400 gas liquid chromatograph using a capillary column and electron capture detector. However, the cypermethrin could not be detected even at 1 m downwind owing to the very low application rate (25 g a.i. ha^{-1} is equivalent to 0.25 µg cm^{-2}).

4.2.2 Statistical analyses

The determinations of LD_{50} from topical dosing with cypermethrin and triazophos were based on probit analyses of the dose response relationships using the Maximum Likelihood Programme (Ross, 1980). The estimates from the separate replicate experiments were pooled to obtain an overall weighted mean estimate as described in Davis, Lakhani & Yates (1991). For field data, estimates of mortality, with standard errors, were required for each distance from the replicate transects. These were obtained by pooling the numbers of larvae exposed at each distance and noting the total number of larvae dying. Thus, using the binomial model, the mortality rate p was estimated by the observed proportion dying, $\hat{p} = \Sigma r_i / \Sigma n_i$

where r_i = number of deaths, n_i = number exposed, at a given distance on the ith transect; and S.E.($\hat{p}$) = $\sqrt{[\hat{p}(1-\hat{p})/\Sigma n_i]}$

The distances at which larvae would be expected to suffer 50%, 20% and 10% mortality were estimated at Upper Caldecote 1 and Swavesey by fitting the generalized logistic model to the data as described by Davis *et al.* (1991a), i.e. $P = \gamma + \delta/[1 + \exp(\alpha - \beta d)]$ where P is percentage dying at distance d.

4.3 RESULTS

4.3.1 Laboratory toxicity tests

Cypermethrin was found to be the most toxic of the ten compounds so far tested against *Pieris brassicae*, being nearly 100 times as toxic as endosulfan (used for standardized comparisons in Sinha, Lakhani & Davis, 1990), 6.6 times as toxic as triazophos and 3.8 times as toxic as diflubenzuron used in earlier drift trials (Tables 4.1 & 4.2). The dose response curve for cypermethrin was found to be very steep around the LD_{50} value, i.e. a small change in dose concentration produced a large change in percentage mortality. The above comparisons of relative toxicity are therefore only valid for the LD_{50} dose.

In the case of triazophos, the LD_{50} doses increased with 3- and 4-day-old larvae as expected. When the dose per unit weight is considered, the effective rate was doubled for 3-day-old larvae but showed little further increase for 4-day-old larvae (Table 4.1).

Contact toxicity in the field, however, is determined as much by application rate (and formulation) as by intrinsic toxicity. Thus Table 4.2 shows that the 'hazard index' for cypermethrin is comparable with that for diflubenzuron and about 40% of that for triazophos at the rate used on peas. All three compounds also act as stomach poisons so the actual field toxicity may often depend on feeding behaviour rather than on direct exposure to spray drift.

4.3.2 Drift trial at Monks Wood

The pilot drift bioassay with cypermethrin at Monks Wood gave results that were comparable with those obtained for diflubenzuron, at a wind speed of 2.5 m s^{-1} (Davis *et al.*, 1991a), in that 20% mortality lay between 5 m and 10 m downwind for the youngest group of larvae (Table 4.3). However, it should be noted that even those larvae were a day older than in the standard diflubenzuron trials, and secondly that there was not a great difference in sensitivity among the three age groups. The lack of clear-cut differences in this drift trial may have been due partly to the limited sample size (a single transect for each age group), but also to the greater consumption of pesticide residues, and therefore increased stomach poisoning mentioned above.

4.3.3 Crop spraying bioassays

Site details

Six spraying operations were studied, one in 1989 and five in 1990. Table 4.4 summarises site, spraying and meteorological variables.

Table 4.1. Toxicity of cypermethrin and triazophos in topical applications to *Pieris brassicae* larvae. LD_{50} estimates from probit analysis ± standard errors as % of the estimates.

Insecticide	Larval age (days)	Concentration (%)	± SE	µg/insect	µg/g
Cypermethrin	2	6.48×10^{-5}	6.5	0.00016	0.231
Triazophos	2	4.26×10^{-4}	7.7	0.0011	1.521
"	3	10.55×10^{-4}	5.3	0.0026	3.103
"	4	17.86×10^{-4}	6.0	0.0045	3.283

Table 4.2. Relative field hazard of 4 insecticides to 2-day-old *P. brassicae* larvae based on topical dose and application rate (active ingredient) to field crops.

Insecticide	LD_{50} (µg/g)	Field rate (g/ha)	"Field hazard" = Rate/LD_{50} (million LD_{50} units/ha)
Dimethoate	627	400	0.6
Cypermethrin	0.23	25	108
Diflubenzuron	0.87	100	115
Triazophos	1.52	336*	221

* rate for peas; 1050 for carrots (full rate).

Table 4.3. Pilot drift bioassay trial with cypermethrin at Monks Wood. Percentage mortality in three age groups of *P. brassicae* larvae.

Date/time 6 July 1990/1445 Wind speed 3 m s^{-1}

	Age (days)		
Distance (m)	3	5	7
0	100	100	100
2.5	31.3	14.3	40.0
5	41.7	17.1	17.4
10	16.0	18.2	8.3
20	6.3	8.9	5.4
30	3.4	2.0	4.2
Controls	5.6	4.8	0
Mean larvae/station	28	43	25

An aphicide, demeton-S-methyl or dimethoate, was included in the spray at Upper Caldecote and Swavesey. Previous bioassay experiments have shown that these compounds have a very low toxicity to *P. brassicae* compared with cypermethrin and triazophos (Williams *et al.*, 1987; Sinha, Lakhani & Davis, 1990). The width of sprayed area upwind of the targets depended on the combination of boom width and number of passes. Drift from a single pass was assessed at Haverhill and Swavesey where the tractor started working from the far end of a large field after spraying the headland. At Upper Caldecote the tractor made three or four passes before the targets were taken up. At Chatteris the targets were exposed to drift from seven passes covering the whole field. However, there was some doubt as to whether the sprayer was giving the expected output at this last site because of calibration problems and the amount of spray left in the tank.

The downwind terrain varied considerably from site to site, and depended on wind direction on the day. Most crops adjoin other crops, with or without an intervening grass bank, hedge or ditch, but it just happened that the downwind edge on five of the six occasions bordered a road or track. The time of spraying varied between 0940 and 1810, modal wind speed from 2.5 to 5.0 m s^{-1} and temperature from 16° to 23°C (Table 4.4). There was a light drizzle during spraying on the first occasion at Upper Caldecote so no water-sensitive papers were used there.

Drift effects

The percentage mortality data for *Pieris brassicae* larvae (Table 4.5) are arranged in seven distance classes to aid cross comparisons among sites, the actual spacing of targets being largely determined by physical and vegetation features. As mentioned previously, the results for the first Haverhill trial were atypical as the larvae were too young to survive exposure well, confirmed by the heavy mortality in the controls. The controls at Chatteris also showed somewhat higher mortality than usual, which was probably the result of strong winds and unusually long exposure when the whole field was sprayed.

These six cases are depicted in semi-diagrammatic form (Figures 4.1-4.5) to show the mean mortality curves superimposed on the ground features. (As mentioned above, the targets were placed on the ground in all cases except in the field of beans.) At Haverhill, Chatteris and Upper Caldecote 2 the mean mortality profiles were approximately straight lines over the range of distances considered (Figure 4.1, 4.2, 4.4). The mortality levels at Chatteris were lower at 1 m and 5 m than might be expected from the width of sprayed area and rather high wind speed; they were more comparable with those at 6 m and 11 m at Upper Caldecote 2. This might be attributed to wind currents over the raised road between the two targets but deposition measurements on water-sensitive papers do not support this theory (see below). Estimates of distances at which 50%, 20% and 10% of larvae would be expected to die were read directly from the graphs for these three occasions (Table 4.5).

The curve for Upper Caldecote 1 was sigmoid (Figure 4.3), as in the earlier experiments with diflubenzuron at intermediate wind speeds (Davis *et al.* 1991a). The tail of the mortality curve was

Table 4.4. Six field bioassays of insecticide spray drift: site, spraying and meteorological details.

	Haverhill 1	Haverhill 2	Chatteris	U. Caldecote 1	U. Caldecote 2	Swavesey
Crop	peas	peas	peas	b-sprouts	b-sprouts	peas
Date	28.6.90	10.7.90	16.7.90	29.8.89	27.7.90	11.6.90
Time	1515	1430	1545	1000	0940	1810
Insecticide	cypermethrin	cypermethrin	cypermethrin	cypermethrin*	cypermethrin*	triazophos†
Rate (g a.i. ha^{-1})	25	25	25	25	25	336
Sprayed width (m)	24	24	100	25.5	34	18
Crop height (cm)	55	55	50	50	40	50
Wind speed (m s^{-1})	4.0	3.5	5.0	2.5	2.5	2.5
Temperature (°C)	23	21	20	16	22	16
Nozzles (BCPC code)	Albuz 110V		Chafer Red	Albuz APG 110B		Lurmark 04F 110
Spray pressure (bar)	2.75		2.5	3.6		3.5

* plus demeton-S-methyl at 325 g a.i. ha^{-1}; † plus dimethoate at 350 g a.i. ha^{-1}.

Table 4.5. Six field bioassays of insecticide spray drift: mean % mortality of *Pieris brassicae* (bold figures) at various distances downwind, and distances at which 50%, 20% and 10% mortality would be expected to occur (with standard errors from logistic models).

	Haverhill 1		Haverhill 2		Chatteris		U. Caldecote 1		U. Caldecote 2		Swavesey	
Distance class	Dist	% mort	Dist	% mort	Dist	% mort	Dist	% mort	Dist	% mort	Dist	% mort
0-1	1	**100**	1	**80.6**	1	**34.6**	1	**95.5**	0.8	**67.8**	0	**100**
>1-2	-		-		-		2	**97.6**	-		2	**100**
>2-4	-		-		-		4	**66.6**	-		-	
>4-8	7.5	**79.1**	7.5	**65.3**	5	**25.5**	8	**14.0**	6.1	**33.7**	7	**68.9**
>8-12	-		-		-		-		11.4	**26.8**	10	**23.5**
											11.5*	**1.7**
>12-16	15	**69.6**	15	**47.9**	15	**15.8**	16	**14.3**	-		13.4	**10.3**
>16-25	25	**43.3**	25	**5.6**	25	**7.4**	18*	**1.1**	21.9	**4.0**	-	
Control		**41.9**		**1.3**		**9.0**		**0**		**6.2**		**5.4**
Mean larvae/station	21		39		31		41		33		29	
No. of transects	3		3		3		2		3		4	
LD_{50}	(22.5)†		14.0		<1		5.1±0.7		3.5		8.2±0.3	
LD_{20}			21.6		10.4		7.3±1.2		13.9		10.6±0.4	
LD_{10}			24.0		21.6		8.6±1.7#		18.6		12.0±0.6	

* immediately behind hedge line; † larvae only 1-day-old; # underestimate - at least 16 m as per data, see text.

Figure 4.1. A. Mortality profiles for Pieris brassicae larvae exposed to cypermethrin spray drift from a pea field at Haverhill, Cambridgeshire on two occasions - open circles 28 June closed circles 10 July 1990. Mean values of 3 replicates. B. Equivalent drift deposition measurements on water-sensitive papers. Further details in Tables 4.4 and 4.5.

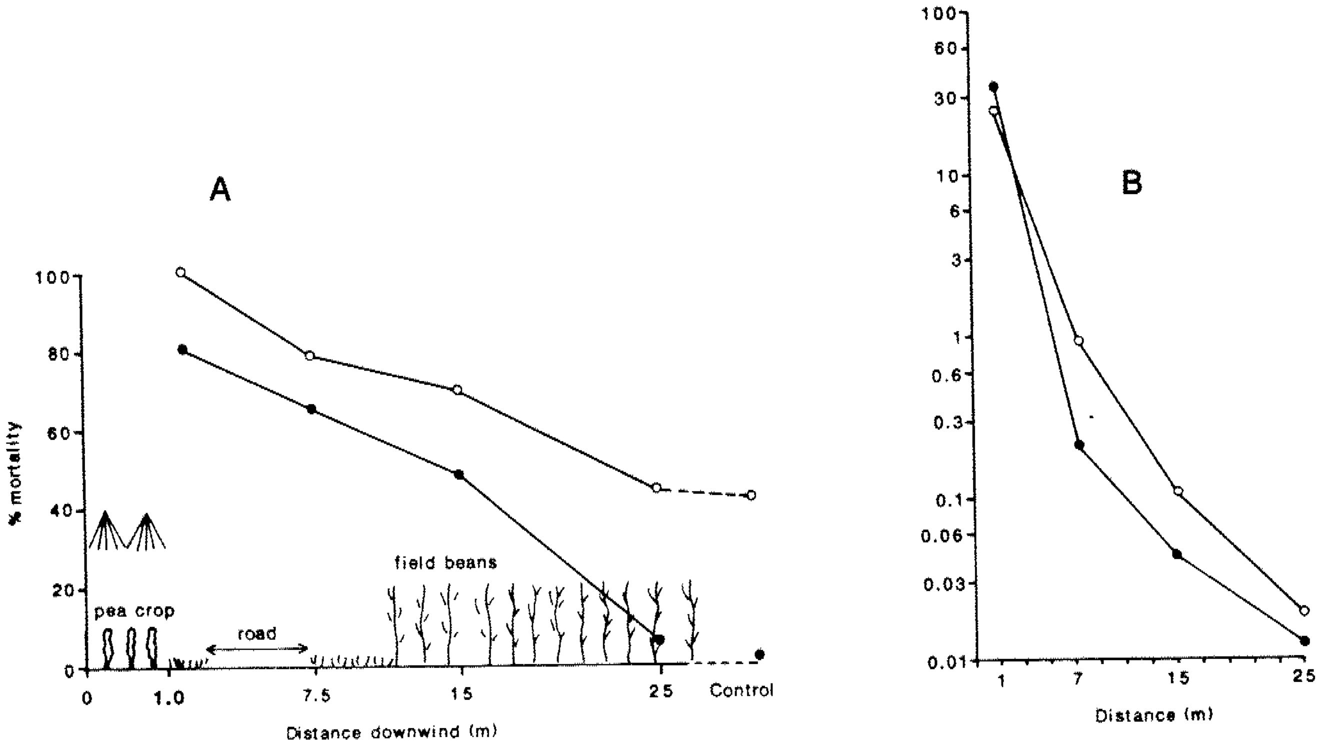


Figure 4.2. A. Mortality profile for P. brassicae larvae exposed to cypermethrin spray drift from a pea field at Chatteris, Cambridgeshire, 16 July 1990. Mean values of 3 replicates. B. Equivalent drift deposition measurements for individual replicates. See Tables 4.4 and 4.5.

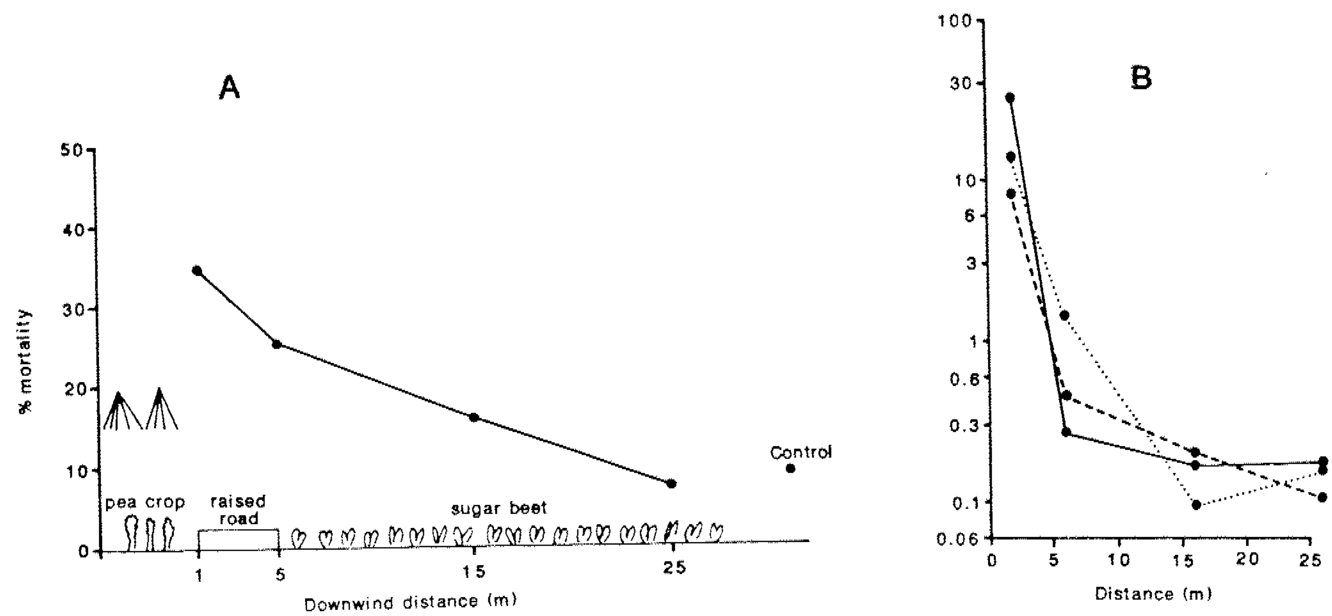


Figure 4.3. Mortality profile for P. brassicae larvae exposed to cypermethrin spray drift from a brussels-sprout field at Upper Caldecote, Bedfordshire, 29 Aug 1989. Means of 2 replicates. See Tables 4.4 and 4.5.

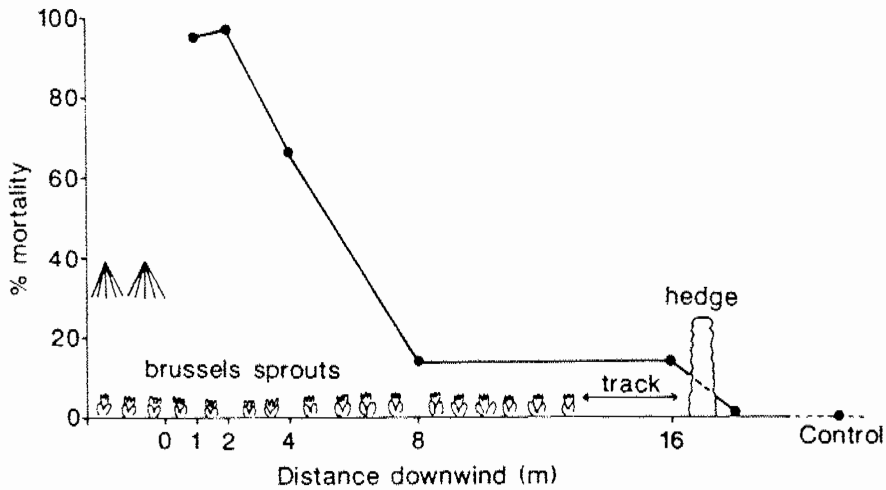
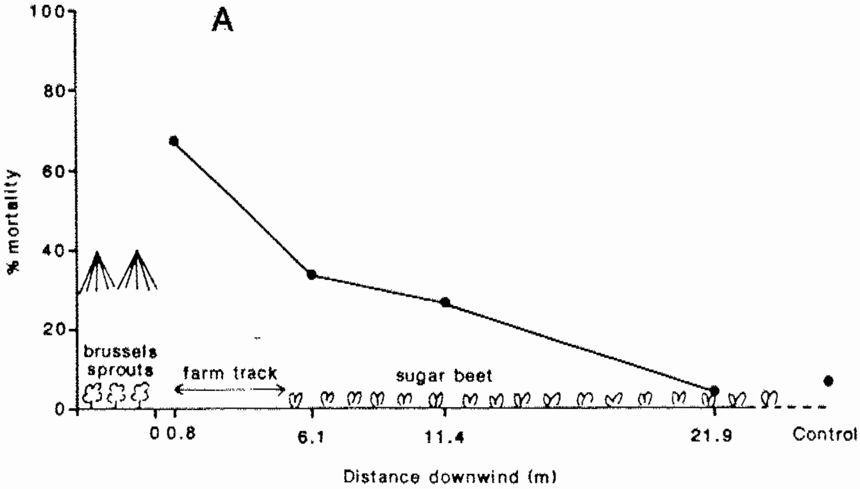


Figure 4.4. A. Mortality profile for P. brassicae larvae exposed to cypermethrin spray drift from a brussels-sprout field at Upper Caldecote, Bedfordshire, 27 July 1990. Means of 3 replicates. B. Equivalent drift deposition measurements for individual replicates. See Tables 4.4 and 4.5.



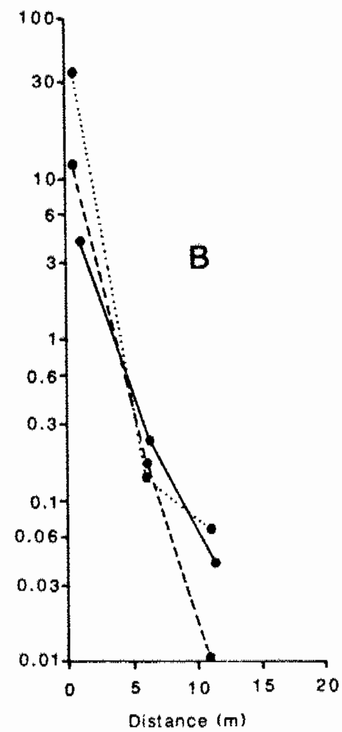
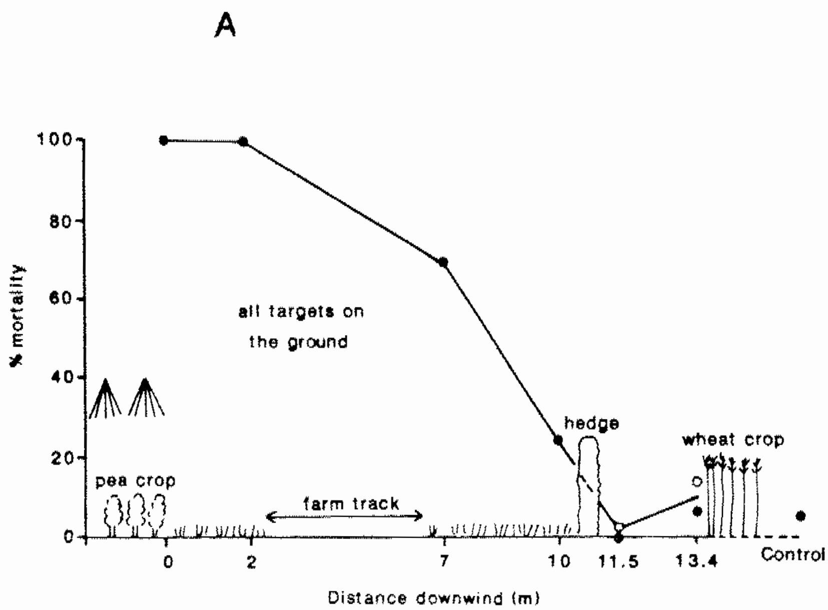
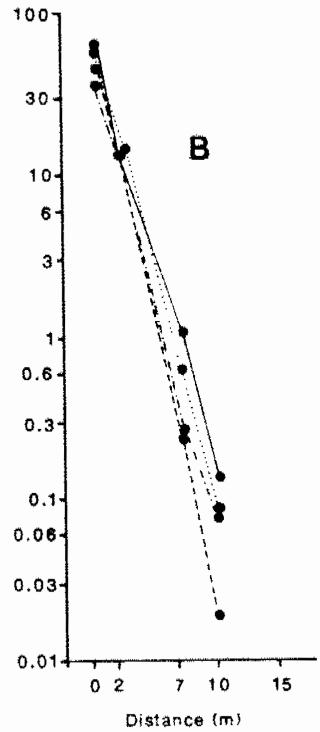


Figure 4.5. A. Mortality profile for P. brassicae larvae exposed to triazophos spray drift from a pea field at Swavesey, Cambridgeshire, 11 June 1990. Means of 4 replicates. Open circles beyond the hedge represent 2 samples opposite gaps. B. Equivalent drift deposition measurements for individual replicates. See Tables 4.4 and 4.5.





considered to be truncated by the shelter provided by a hedge as larvae placed immediately behind it suffered only 1% mortality compared with those just in front with 14%. In fitting a logistic model to the data, the values obtained behind the hedge were therefore excluded. Estimates of LD_{50}, LD_{20} and LD_{10} distances varied by 1-3 m between the two transects but the lowest standard errors were obtained by combining both sets of data. (The use of an extra pair of 'data values', by assuming zero mortality at 64 m, made virtually no difference to the estimated parameters.) The fitted relationship between percentage mortality (P) and distance (d) was $P = 107.73/[1 + \exp(0.618d - 3.034)]$.

Swavesey was the only site where triazophos was used (with dimethoate). The mortality curve here was even more convex over the first 10 m and a hedge again appeared to have some effect (Figure 4.5). Two of the four lines of targets were placed opposite small gaps. Tall grass in these gaps sheltered targets placed just behind the hedge line but those placed 2 m further away on bare ground in front of a wheat crop had a higher average mortality (14%) than those that were sheltered by the hedge (7%), although the replication was insufficient to show significant difference. For fitting the logistic model here, the values immediately behind the hedge line were again excluded but the furthest values were retained. In Table 4.5 the results are based on the combined data from all four transects and are obtained from the fitted relationship $P = 101.95/[1 + \exp(0.582d - 4.759)]$.

Figures 4.1-4.5 also show the drift deposition results obtained from the water-sensitive papers placed adjacent to the larvae. These deposition curves, plotted on log-normal axes, show rapid and almost linear decline up to about 10 m at Swavesey and Upper Caldecote 2, but a more exponential fall-off at Haverhill and Chatteris. The similarity between the two spraying events at Haverhill is noteworthy. The results for Chatteris show greater drift at 15 and 25 m downwind, as would be expected from the higher wind speed, although this was not reflected in higher mortalities of larvae.

4.4 DISCUSSION

Studies of spray drift done under commercial farming conditions are subject to many uncontrollable factors. Uncertainty in timing can prove a serious impediment to bioassay studies when these depend on using animals or plants at a critical, sensitive stage. In this respect, the standardized procedure used here with 2-day-old *P. brassicae* larvae requires the spraying date to be known, and fixed, 5-7 days in advance, whereas farmers and contractors must normally respond flexibly to changes in weather, pest status and problems with equipment. The production of large numbers of larvae to order depends on a reliable external source of eggs or good quality control in an in-house breeding programme. Given these constraints, and the possibility that a bioassay trial may have to be aborted at the last minute, the studies reported here nevertheless demonstrate that the method can be used under a range of field conditions.

In the studies described, the large variation between spray events - in site, operator and meteorological variables - prohibits precise conclusions about the effects of any particular variable. The height of vegetation downwind of the sprayed crop varied considerably: from zero, where there was a track or road, to 40-

50 cm for the sugar-beet at Upper Caldecote 2 and Chatteris, and 120 cm for the field beans at Haverhill. The tall beans would have deflected the drift cloud upwards creating turbulence for a considerable distance (cf. Bradley, 1968). Such changes in "roughness length" and the presence of hedges makes it unrealistic in many field situations to expect the drift deposition and mortality curves to fit a simple logistic or exponential model, as was assumed in the experiments done over a uniform grass sward (Davis *et al.*, 1991).

Under such circumstances, a combination of modelling with graphical determinations (Fig. 1) allows reasonable estimates of buffer zones to be made under the prevailing spraying and topographical conditions. If these are set by distances at which larval mortality was ≤10%, then trials 2, 3 and 5 give similar estimates of the order of 16-24 m. These results are comparable with the higher estimates of LD_{10} distance in Davis *et al.* (1991) for diflubenzuron which were in the range 16-28 m. For cypermethrin in trial 4, an LD_{10} estimate of 8.6 m, using the logistic model, is clearly an underestimate, because the field observations showed mortality of 14% up to the hedge at 16 m. For triazophos at Swavesey, a similar hedge effect produced an LD_{10} value of 12 m. These estimates make no allowance for control mortality of about 5% and should therefore be treated with caution. On the other hand, they are based on short-term mortality and do not take account of delayed or sublethal effects.

Longer-term effects need to be studied to obtain estimates of the dosage levels or distances at which there is no detectable effects on fecundity. To be realistic, however, studies should also take account of behaviourial response to sprays. The hazard of pyrethroid sprays to honeybees is reduced because their repellency results in avoidance behaviour (Shires, 1983). Similarly, *Pieris brassicae* larvae can show irritancy responses to pyrethroids (Tan, 1982) which could cause them to drop off a plant. This might reduce exposure to toxic residues but increase exposure to ground predators which are the main cause of larval mortality in brassicas (Dempster, 1968).

Water-sensitive papers are useful for assessing deposition of larger droplets (MacCollom, Currier & Baumann, 1986), but should only be used in the absence of a more precise method such as a tracer dye or element (see Section 6). Only 30% of drops 50 µm in diameter will impact on glass microscope slides in a 2 m s^{-1} wind (Byass & Lake, 1977), while Davis *et al.* (1991) showed that mortality of *Pieris brassicae* larvae occurred beyond the distance at which drift could be detected on water-sensitive papers. However, tracers cannot generally be added to commercial spray operations.

In extrapolating these results more widely, the following factors need to be borne in mind. Cypermethrin and triazophos are among the most toxic compounds to the test insect, so less toxic ones would be safely accommodated within these buffer zones. Similarly, a hedge or shelterbelt within 20 m can provide significant protection to habitats beyond (see Section 6). On the other hand, cumulative drift from a whole field was only examined at Chatteris but could add significantly to drift in some circumstances (Nordby and

Skuterud, 1974). Likewise, stronger winds and spraying of taller crops than those studied could increase the amount of drift.

A 10% mortality level for *Pieris brassicae* larvae is, of course, quite arbitrary, and the estimated buffer zones are considerably greater than the 6 m "conservation headland" recommended by the Game Conservancy for increasing the invertebrate food of partridge chicks. The Conservancy's figure is based pragmatically on the width of spray boom that can conveniently be shut off when spraying around the edge of a field, and will certainly reduce drift into field margins (Cuthbertson, 1988; Cuthbertson & Jepson, 1988). Bioassay measurements with *P. brassicae* indicate that mortality at 6 m would be between 24% and 39% for trials 3-5 and 70-75% for trials 2 and 6. However, such comparisons are not strictly applicable because the first 6 m in the present studies were generally over a roadway or short vegetation. Less drift could be expected to occur over the same width of cereal crop.

ACKNOWLEDGEMENTS

We are grateful to Messrs M Haylock, C Childs, P Maudlin and J Burgess for affording us access to their land and their helpful co-operation. We would also like to thank ICI and Hoechst UK for supplying technical grade cypermethrin and triazophos.

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