1.5 FENITROTHION (2)

1.5.1 Methods

Spraying and sampling
The same field was used as for triazophos but it was under wheat in 1993, and since there was a westerly wind the eastern third was sprayed (Figure 1.19).

As before, three lines of cabbage plants and two lines of water traps were laid out downwind of the east edge of this field, across a fallow field about 160 m wide, and then across another wheat field to a total distance of 350 m. Both types of target were also placed at a distance of 30 m into the sprayed crop, ie immediately under the first swath. The plants had on average 23 2-day-old *P. brassicae* larvae.

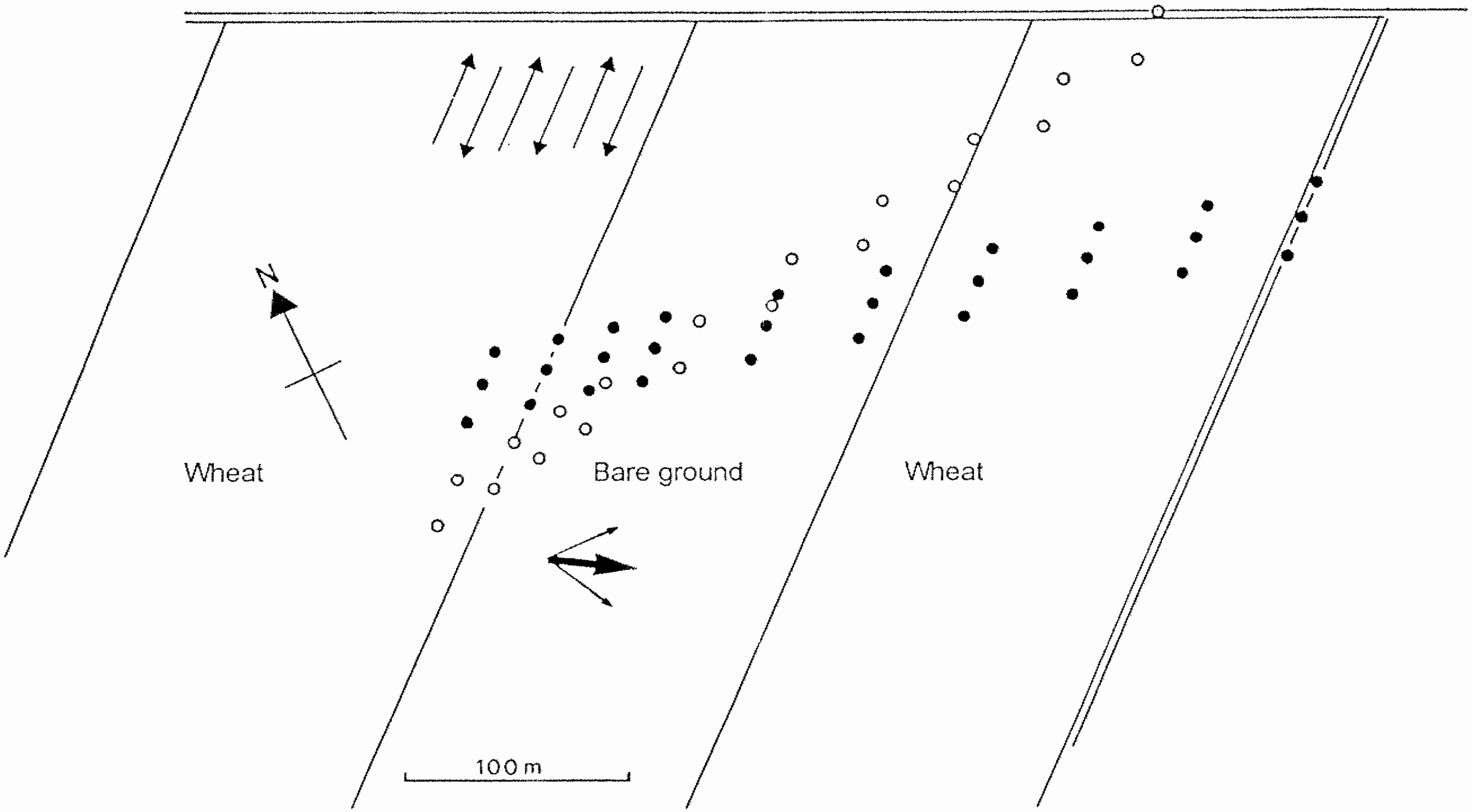
Water-sensitive papers were pinned to canes next to the cabbage plants in the central line of targets to provide a visual record of drift deposition.

The wind direction veered early during this setting out process and the two types of target followed different lines (Figure 1.19). The downwind distances for the water targets are therefore adjusted in the following results but not those for the cabbage plants whose alignment was considered to fall within the normal variability in assessing wind direction from the anemograph trace.

The wind was fresh, Beaufort force 4, and therefore marginal for aerial spraying (other commercial spraying operations had been suspended). However, ground sprayers were active in two fields downwind using aphicides. Eight swaths were sprayed, the middle of the first swath being 26 m from the edge to allow for the wind.

Bioassays
The caterpillars were checked for mortality the same afternoon, three to six hours after spraying, and then daily for six days when the effects appeared to have stabilised. Twenty *Gammarus pulex* per tray, were exposed to the possibility of fenitrothion drift in the field. Following spraying these were transferred to the laboratory and kept in water from the appropriate tray, for up to six days. Other *Gammarus*, 10 per 250 ml beaker, were exposed in the laboratory to samples of potentially contaminated water from each of the targets as well as to samples that had been diluted to simulate the concentration of pesticide that would have resulted, under similar circumstances, with a target-depth of 25 cm. *Asellus aquaticus* (10 per beaker) and *Culex torrentium* larvae (20 per beaker) were also exposed to water samples from the trays. Paired controls, using water from the same source, but not exposed to the possibility of drift, were established for each species. All were kept under cover and in shade, but out of doors and therefore at ambient summer air temperatures, for the duration of the experiments.

Figure 1.19. Fenitrothion (2) trial. Positions of *Pieris* ● and aquatic ○ targets, spray swaths → and wind direction ➡



Gammarus, exposed in the field, were checked after one hour and four hours and at 24 hour intervals thereafter. Dead animals were counted and removed from the containers. Those *Gammarus*, that were only exposed to water samples in the laboratory, along with the *Asellus* and *Culex*, were first examined after 21 hours and subsequently at daily intervals.

1.5.2 Results

Water-sensitive papers
There was visual evidence of drift deposition on the water-sensitive papers up to 100 m, viz:

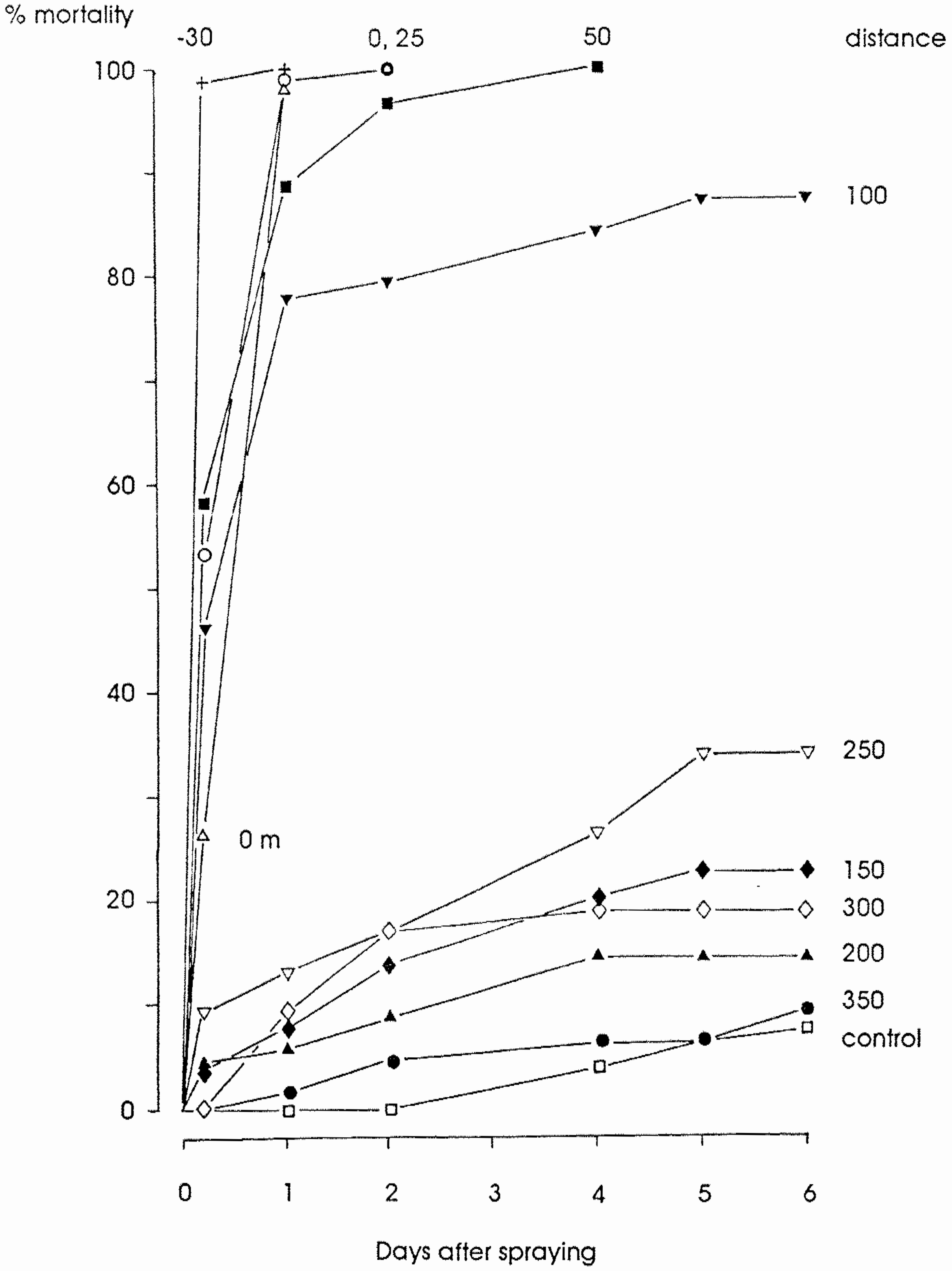
Downwind distance (m)	-30	0	25	50	100
% cover of spots	13.6	0.55	0.413	0.051	0.011
no. of spots	1546	178	123	18	5

These figures indicate that deposition at the edge of the sprayed crop was about 4% of that under the plane and about 0.4% at 50 m into the fallow field.

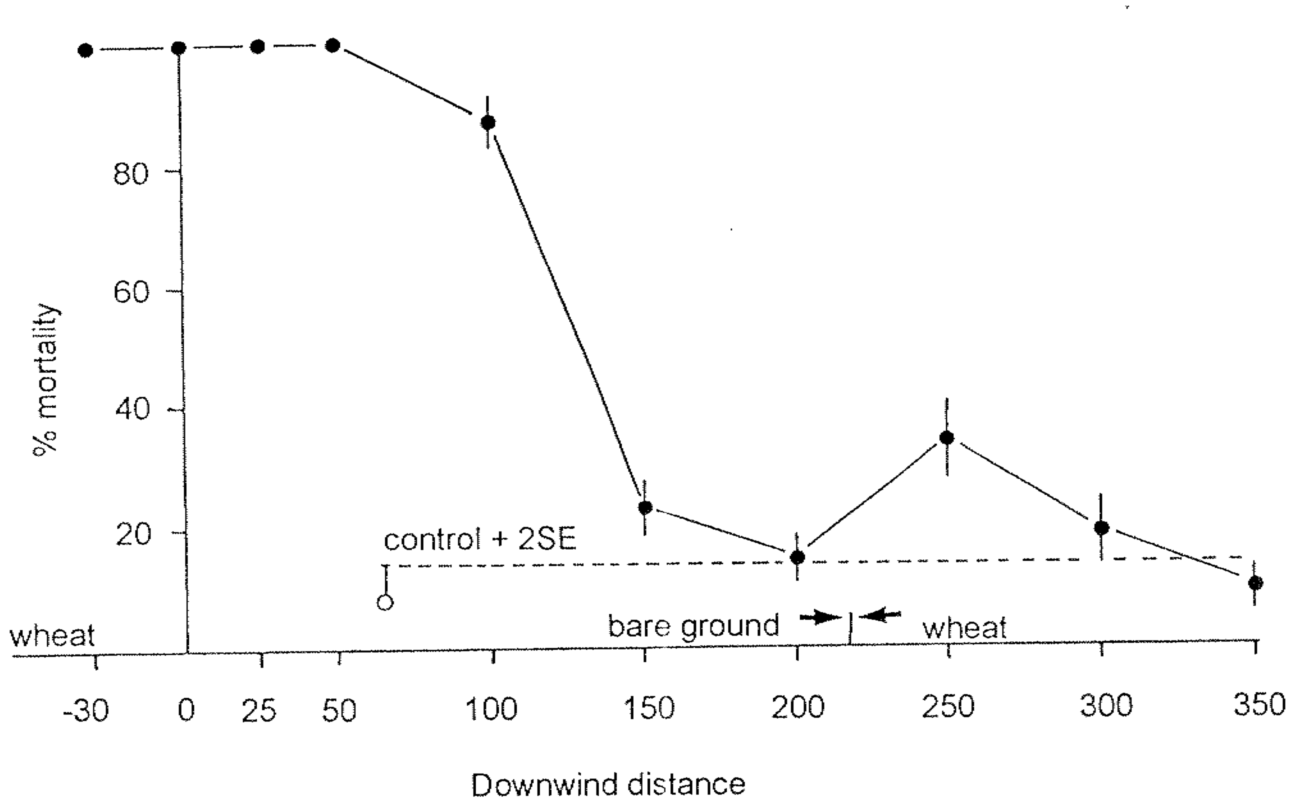
Caterpillars
The caterpillars exposed to drift at the nearer distances (up to 100 m) showed an even more rapid response than those in the triazophos trial, with 46-58% mortality after a few hours and 78-100% mortality after one day (Figure 1.20). However, the cumulative mortality over six days was much less for the targets at 150 m and beyond, leading to a characteristic sigmoid mortality curve with distance, and a "no effect" value at 350 m when compared with controls (Figure 1.21). The mean mortality at 200 m, 16 m before the end of the fallow field, was also quite low (14.5%) and within two standard errors of the control mortality. Mortality appeared to increase again at 250 m in two of the three replicates and it is not clear whether this can be attributed to a greater concentration in the drift cloud after rising over the wheat or to some other factor.

Aquatic invertebrates
Distances of targets downwind of the crop, when recalculated to compensate for the shift in wind direction, were 15, 30, 60, 90, 120, 150, 180 and 210 metres. All of the *Gammarus* that were exposed in the field within the sprayed crop, died within four hours and 88% were dead after only one hour. Mortality was also high among those exposed at the edge of the crop and those 15 m downwind, all of which were dead after 48 hours (Figure 1.22). Substantial mortality occurred among individuals that were placed 30 m downwind, where 52% died after four days, but at 60 m mortality was no greater than in the controls (2%) and none of the animals exposed at a distance of 90 m died and neither did they show any sign of impaired activity. Higher than expected mortality occurred among animals exposed at distances of from 120 to 180 m (Figure 1.22).

Figure 1.20. Fenitrothion (2) trial. Cumulative daily mortality among *P. brassicae* larvae exposed at different distances downwind.



1.21. Fenitrothion (2) trial. Mortality among *P. brassicae* larvae (mean ± SE) after 6 days



A similar pattern of mortality occurred to 60 m, among *Gammarus* that were exposed to water samples in the laboratory. Mortality rates greater than those in the controls (5%) only occurred up to 30 m (Figure 1.23). In water samples that had been diluted to simulate a depth of 25 cm, mortality exceeded that in controls only in water from targets within the crop, where all *Gammarus* died within two days. Otherwise, no mortality could be attributed to the effects of the fenitrothion - even in water from the very edge of the crop.

Asellus were somewhat more susceptible to the effects of fenitrothion drift than *Gammarus*. With the exception of one individual at 15 m - which remained alive, though almost totally paralysed, throughout the experiment - all *Asellus* exposed to target water from 30 m or less died within three days. At 60 m 60% died by day 4 but there was practically no mortality, or evidence of impairment of activity, beyond this distance (Figure 1.24).

Among *Gammarus* and *Asellus* virtually no mortality occurred after the fourth day, although observations were maintained for six days in each case. *Culex* larvae, however, were much more susceptible than either of the crustaceans and deaths continued to occur for the full period of observation. On day 6, however, deaths also occurred for the first time among the controls. All larvae died within three days at all distances up to 60 m (Figure 1.25). In samples of water from 90 and 120 m downwind, mortality reached 60%, or thereabouts, by the sixth day. At greater distances there was either no mortality (180 m) or eventual mortality did not exceed that in the controls (6%). However, other than in the controls and at 210 m, no cast exuviae were observed, suggesting that there may have been impaired development or suppression of ecdysis to as much as 180 m downwind.

Figures 1.26 to 1.29 show the total mortality at each experimental distance, after four days (*Gammarus* and *Asellus*) or six days (*Culex*). If the unexpectedly high levels of mortality among *Gammarus* at distances greater than 90 m are disregarded, the results from the two *Gammarus* trials are very similar (Figures 1.26 and 1.27, with mortality declining rapidly beyond 15 m to 10% or less at 60 m. The 4-day LD_{50} distance for *Gammarus*, under these conditions is between 30 and 40 m. In the case of *Asellus* this distance (Figure 1.28) is somewhat greater than 60 m while for *Culex* (Figure 1.29) it is close to 120 m.

Figure 1.22. Fenitrothion (2) trial. Cumulative mortality among *Gammarus* exposed in the field.

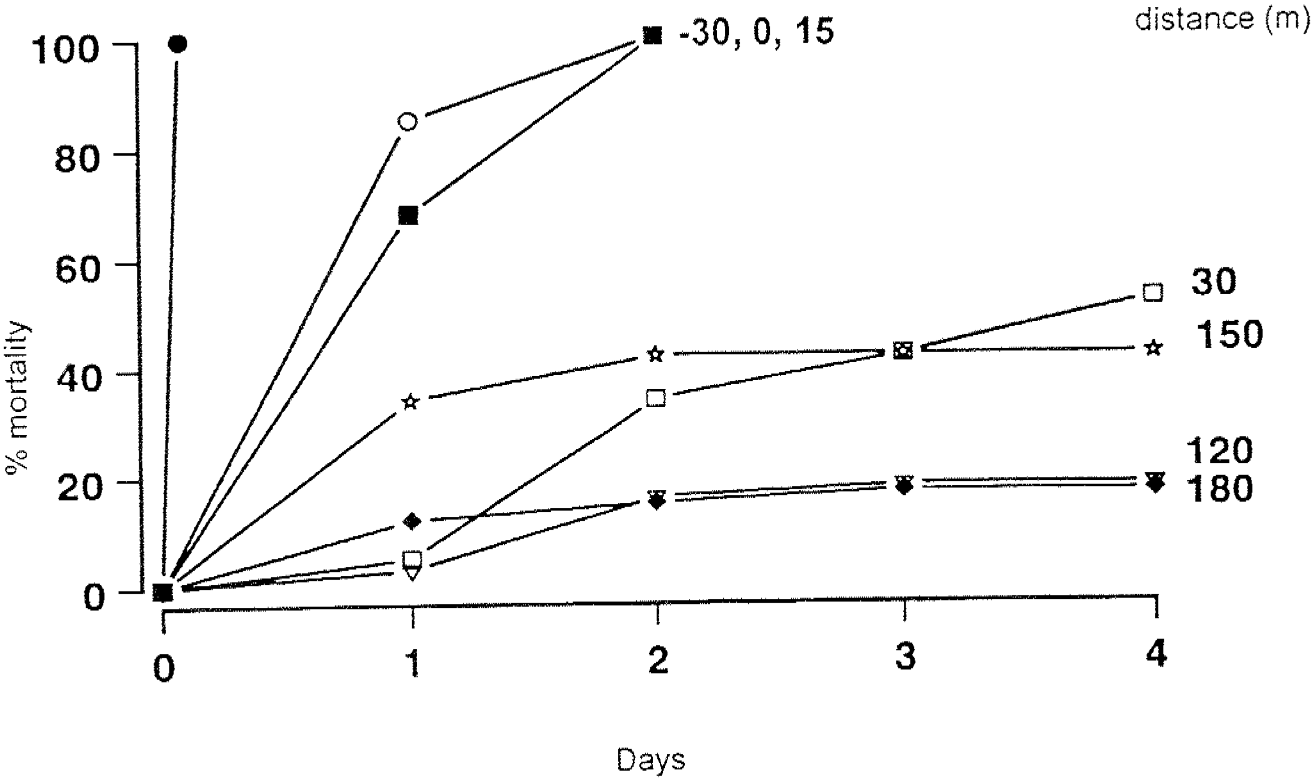


Figure 1.23. Fenitrothion (2) trial. Cumulative mortality among *Gammarus* exposed to water samples that have been subjected to drift.

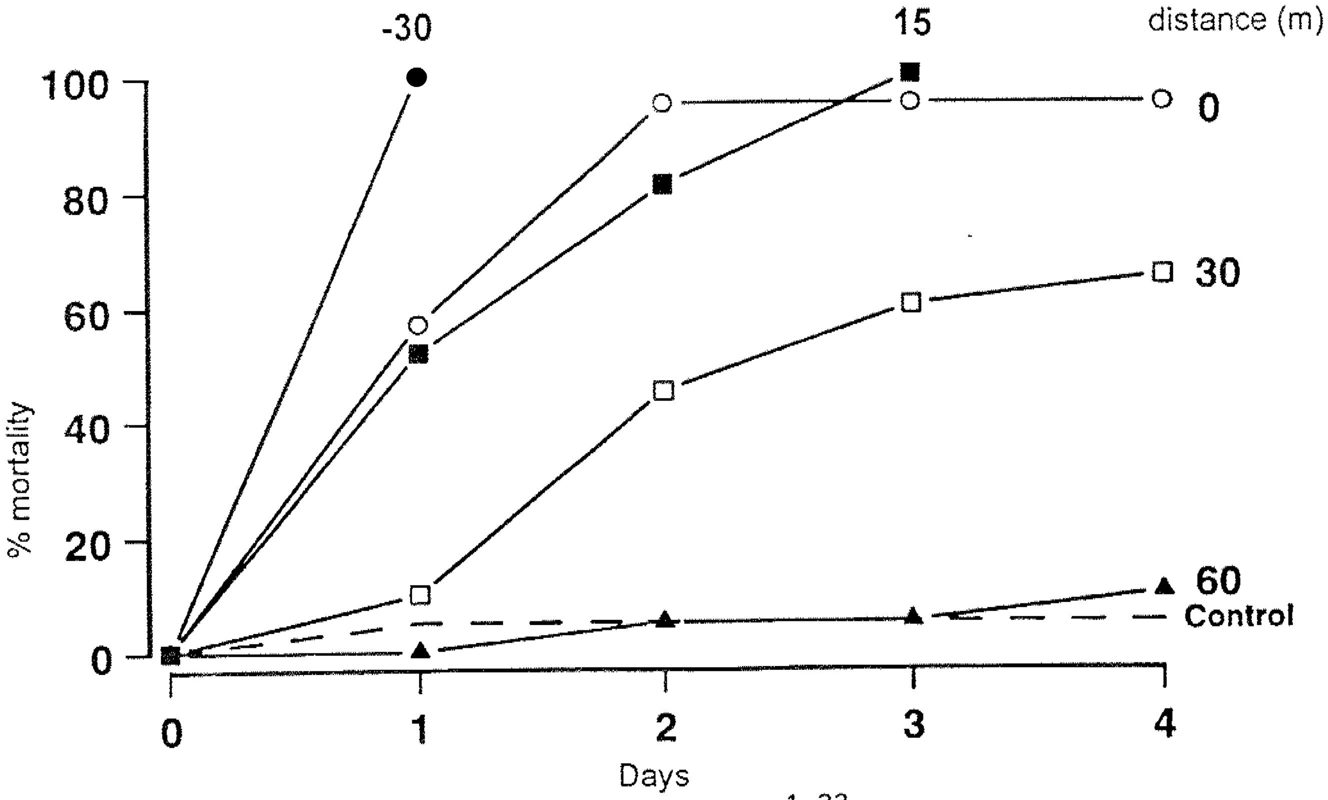


Figure 1.24. Fenitrothion (2) trial. Cumulative mortality among *Asellus* exposed to water samples that have been subjected to fenitrothion drift.

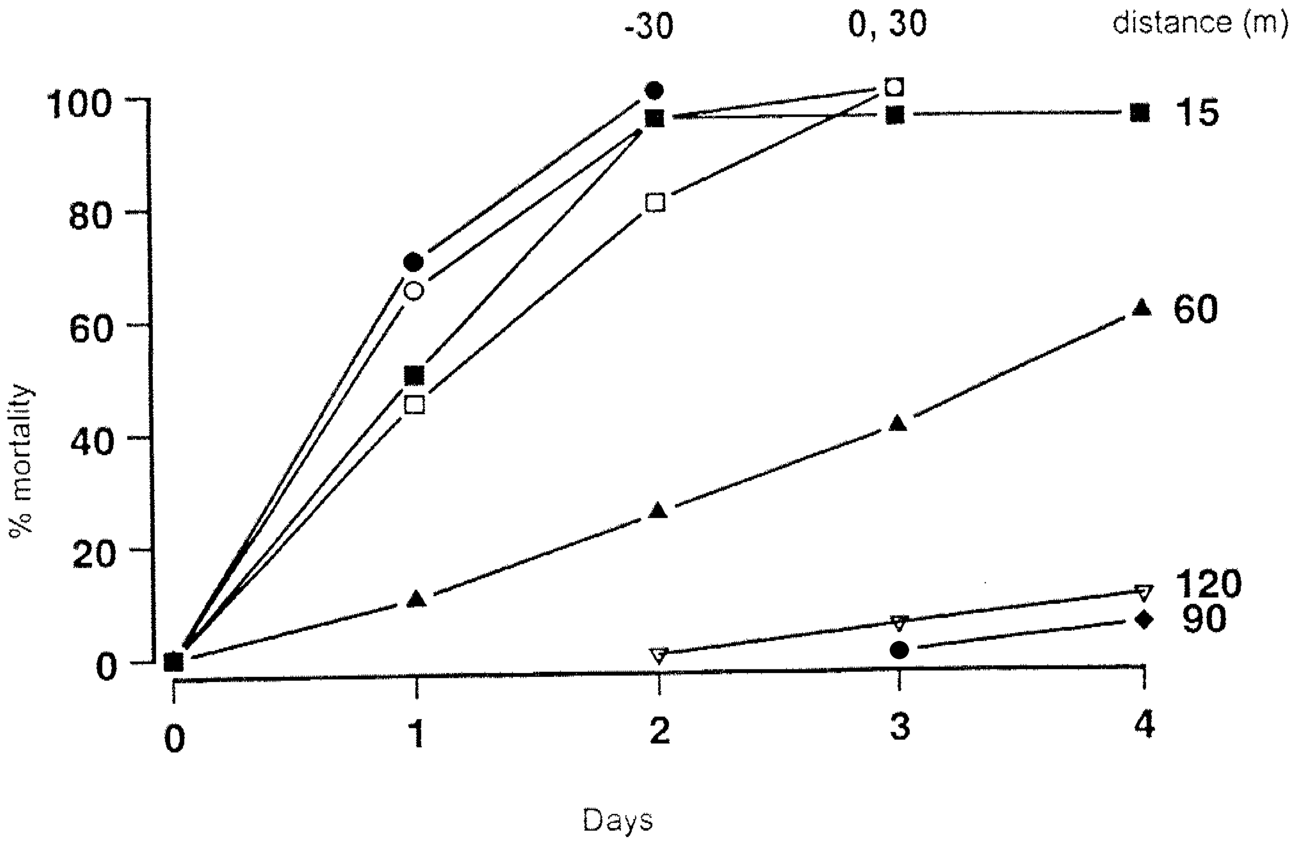


Figure 1.25. Fenitrothion (2) trial. Cumulative mortality among *Culex* larvae exposed to water samples that have been subjected to drift.

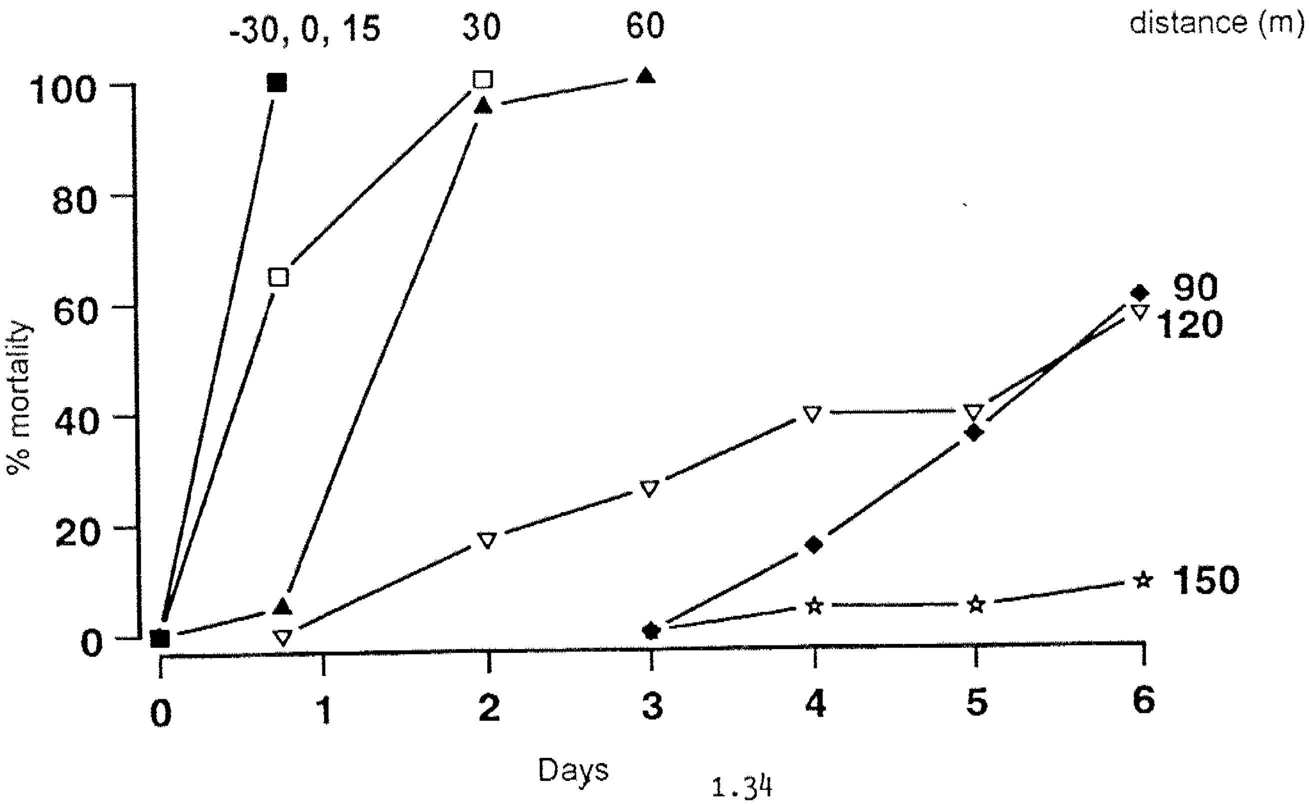


Figure 1.26. Fenitrothion (2) trial. Mortality among *Gammarus*, 4 days after exposure in the field to drift.

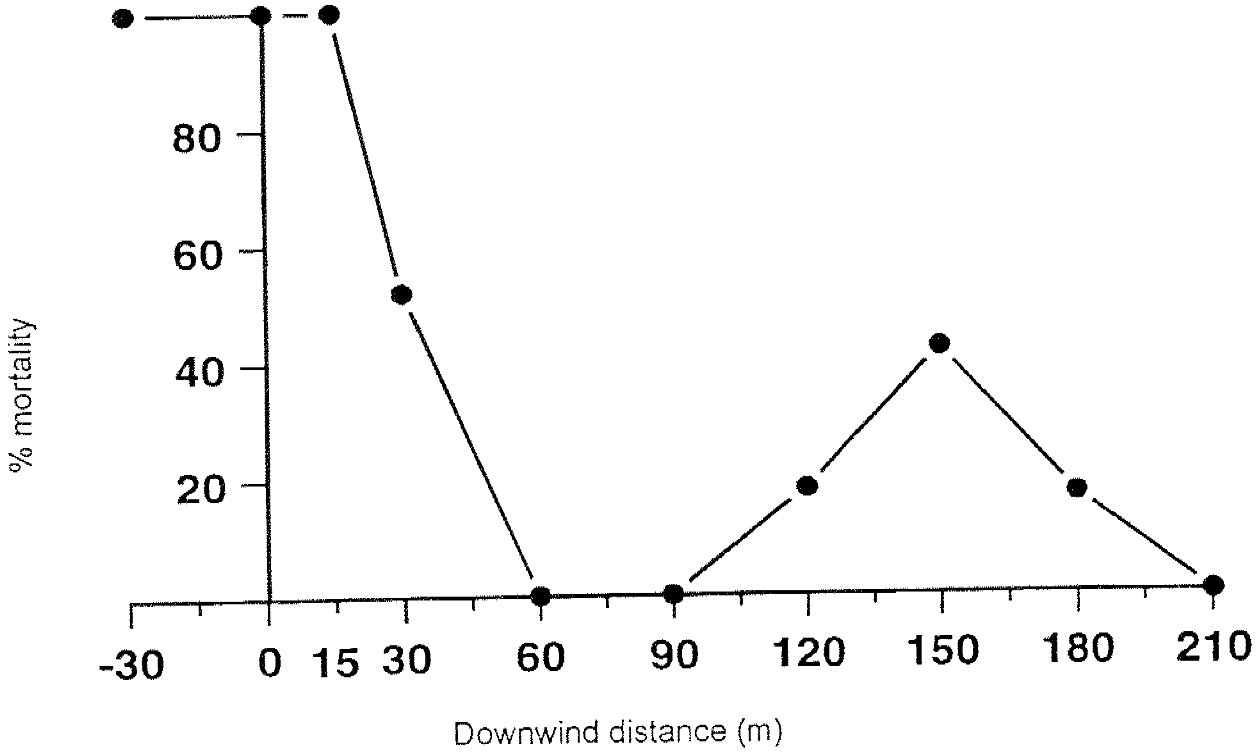


Figure 1.27. Fenitrothion (2) trial. Mortality among *Gammarus* after 4 days in water samples exposed to drift.

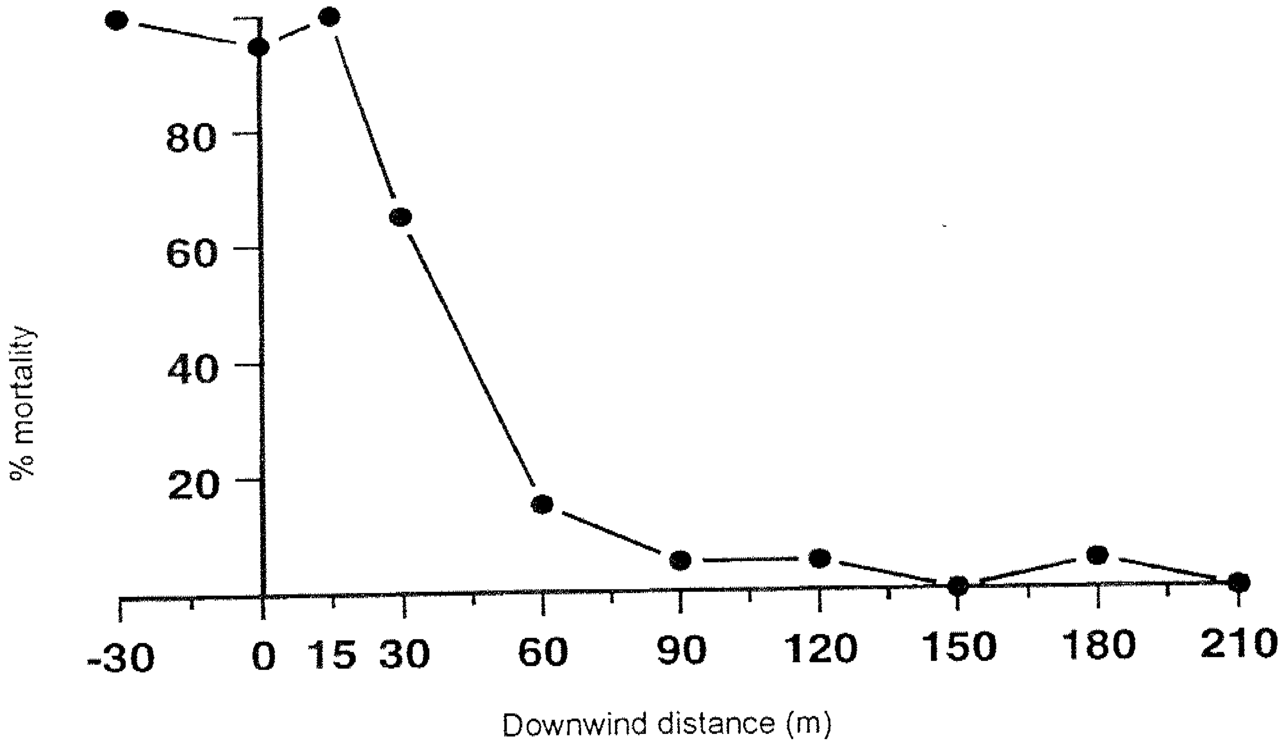


Figure 1.28. Fenitrothion (2) trial. Mortality among *Asellus* after 4 days in water samples exposed to drift.

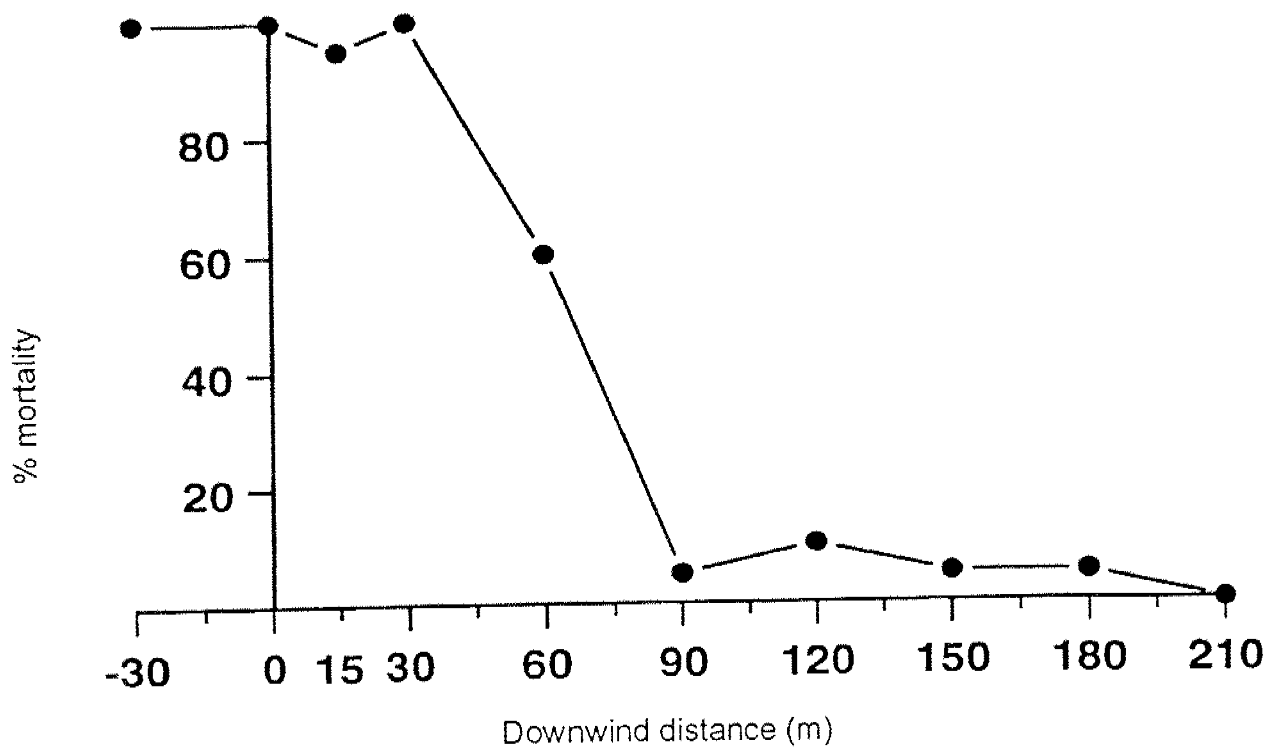
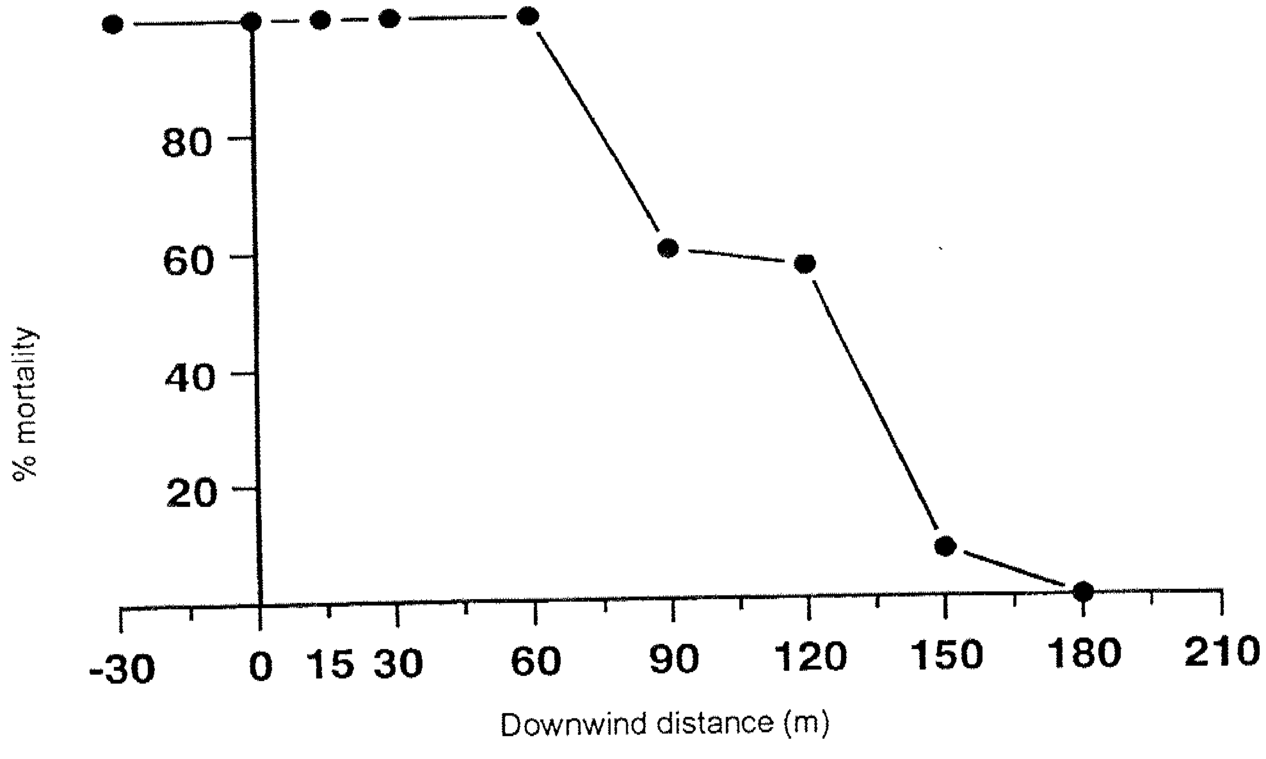


Figure 1.29. Fenitrothion (2) trial. Mortality among *Culex* larvae after 6 days in water samples exposed to drift.



1.5.3 Discussion

This trial (chronologically the last) went smoothly and gave reliable results under conditions that could be considered a "worst case" for drift of a highly toxic, broad-spectrum insecticide under windy conditions. For *P. brassicae*, a buffer zone of 200 m over level ground would appear to be adequate to reduce mortality to the levels of control + 2SE (14.5%). However, the increased mortality above the wheat crop indicates that a buffer zone of 300 m might be required.

The higher than expected number of deaths among *Gammarus* which were exposed in the field at distances of 120-180 m is thought not to be attributable to the effects of spray drift. They were most probably the result of low oxygen concentrations, arising from the death of just one or two animals initially, although every effort was made to remove dead animals as quickly as possible. After death, *Gammarus* decompose very rapidly, inevitably leading to a large increase in BOD and a fall in oxygen concentration within the experimental containers. Although no measurements of oxygen concentration were made, this explanation is supported by the fact that almost all of the deaths occurred during two successive nights and that, in each case, only one of each pair of samples was affected. Furthermore, no comparable mortality occurred in either of the other species of experimental animals, both of which were more susceptible to the effects of fenitrothion than *Gammarus*, or among Gammarus that were only exposed to water samples in the laboratory.

The bioassays represent a somewhat worse case than is likely to be encountered in a real field situation. The fact that no mortality occurred among *Gammarus* kept in water samples diluted to simulate an experimental depth of 25 cm, except when these were from within the sprayed area, indicate that fenitrothion drift is unlikely to represent an important hazard to this species. This is probably also true in the case of *Asellus*, which was only a little more susceptible than *Gammarus*. The data for *Culex* suggest that fenitrothion drift may be a more important consideration for insects. These larvae were not exposed in the field so aerial contamination through their breathing siphons at the time of spraying is not a factor which needs to be considered. However, even under the experimental conditions, with very shallow target water, and taking into account the possibility that development was impaired even beyond those distances where larvae were killed, 200 m would provide an absolute safe distance. Under field conditions substantially less than this would be needed.

1.6 PHOSALONE

1.6.1 Methods

Spraying and sampling
About 4 ha of oilseed rape were sprayed with Zolone in the south east corner of a 21 ha block of spring rape on the Abbots Ripton Estate. This area was defined by a fallow field to the south, a ditch with a few trees along the eastern edge, and a strip of game cover on the western edge leading to an old barn. A line of tall canes with fluorescent cards 21 cm x 26 cm was placed across the field near the barn to delimit the northern edge to be sprayed (Figure 1.30).

Because of the trees and the shape of the plot it had been agreed that the spray swaths would be laid down the long axis, ie roughly north-south, whatever the wind direction. Another line of fluorescent cards was therefore placed along the southern edge at 15 m intervals to indicate flight paths. The wind was in fact light and variable but mainly north-westerly and therefore more or less parallel to the proposed flight path.

Two lines of cabbage plants and water trays were laid out to the north, east and south edges of the area to be sprayed, and at 50 m intervals up to a maximum of 150 m (Figure 1.30) to cater for over-spraying as well as drift. Two plants and trays were also placed near the centre of the field to measure the maximum effects of the spray. There were three control plants with caterpillars, exposed 150 m to the west of the sprayed plot. The caterpillars hatched sooner than planned and were therefore four days old at the time of the trial. Dytiscid larvae were used for the aquatic bioassays in addition to *Gammarus* and *Asellus*.

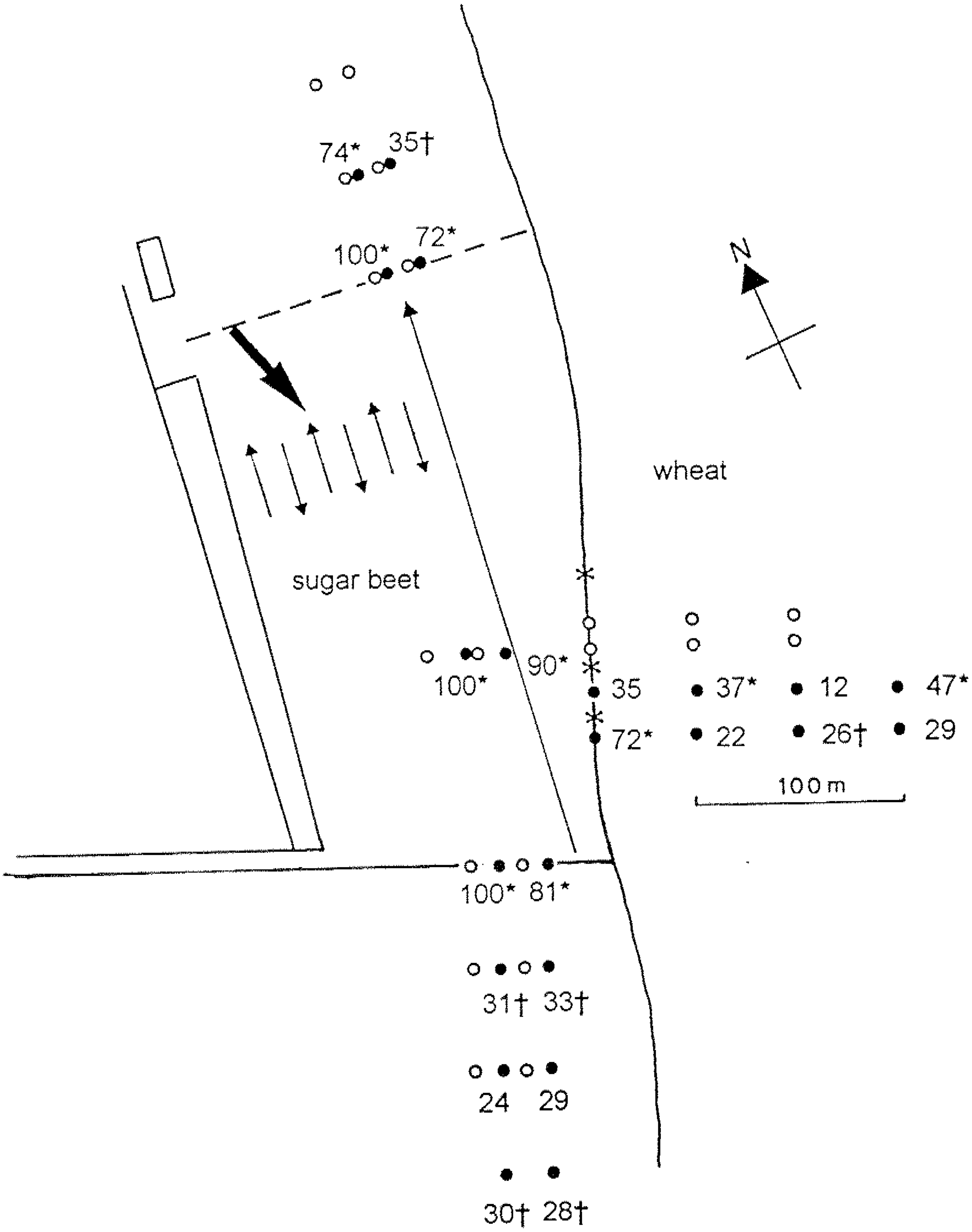
Gammarus were exposed in the field and in the laboratory, where they were placed in undiluted target water and in water diluted to simulate an experimental depth of 25 cm. Mortality among *Gammarus* exposed in the field was first assessed after four hours and daily for four days thereafter. In all other aquatic bioassays the numbers of dead animals were counted daily. Any dead animals were removed.

The plane made eight passes in both directions. The first pass started northwards from the south east corner but appeared to veer away from the east margin of the field in a line more or less parallel with the western edge, and therefore almost directly into the wind (Figure 1.30).

Figure 1.30. Phosalone trial. Positions of *Pieris* ● and aquatic ○ targets, spray swaths, and wind direction. Six-day % mortality results for caterpillars at positions shown.

† = mortality <20% after 3 days but > controls + 2SE for days 4-6

• = mortality >20% after 3 days and > controls + 2SE for days 4-6



1.6.2 Results

Caterpillars
For this trial, the replicate pairs of targets are all considered independently and the bioassays are therefore based on small numbers of animals (average 19). The caterpillars showed slower response to this spray than to deltamethrin, triazophos or fenitrothion; mortality reached 100% after four days in the western replicates on the north and south edges of the plot and in the centre (Table 1.4, Figure 1.30). The eastern replicates of these three positions appeared to stabilise at 72-90% mortality after six days, which supported the view that the plane had flown at an angle to the eastern edge of the field.

A high mortality (74%) was recorded 50 m beyond the northern boundary in the western replicate indicating over-spraying rather than drift. The eastern transects showed a high mortality (72%) only at the field edge in the southern replicate. Mean mortality among controls was 2% after three days, 11% after four days and 14.5% after six days. "Significant" mortality among targets exposed to phosalone is therefore taken to be >20% after two days, or greater than controls + 2SE after four days *and* after six days.

Aquatic invertebrates
The percentages of dead animals in each trial after four days exposure to water contaminated with phosalone are shown in Figure 1.31, and cumulative percentage mortality, at intervals over this period, are listed in Tables 1.5-1.9. All of the *Gammarus* that were exposed to direct spraying within the crop died within four hours. All larvae in targets placed adjacent to the crop on each of the three sides were also killed. Elsewhere mortality was relatively low, except at 50 m (both replicates) on the north side and at 100 m (western replicates only) on the north and south sides.

In a number of instances, (Figure 1.31) higher mortality occurred among *Gammarus* that were exposed only in the laboratory. This was especially noticeable among those exposed to water samples placed to the east of the crop. High rates of mortality also occurred among *Gammarus* exposed to diluted water samples and in some case these were greater than in the undiluted water. The reasons for these anomalies are not clear, but additional stress may well have been imposed by reduced oxygen concentrations in the smaller containers that were used for the laboratory experiments, although no deaths occurred among the control animals.

The pattern of mortality among *Asellus* was similar to that observed among *Gammarus* exposed in the field, although *Asellus* seemed to be somewhat less susceptible than *Gammarus* to phosalone (Figure 1.31).

Data for the Dytiscidae varied somewhat erratically, sometimes showing higher, sometimes lower, mortality than either *Gammarus* or *Asellus* (Figure 1.31). These data are probably influenced by predation of the small larvae upon one another and are therefore unreliable as an indication of the effects of the phosalone drift.

Table 1.4. Phosalone trial. Cumulative % mortality among 4-day-old *P. brassicae* larvae at each position shown in Figure 1.30.

Position	Replicate	Dist	Days after exposure				
			1	2	3	4	6
In crop	W		37	48	70	100	100
	E		48	71	90	90	90
North	W	0	0	71	82	100	100
		50	5	5	26	58	74
	E	0	11	33	39	72	72
		50	18	18	29	29	35
South	W	0	22	61	83	100	100
		50	6	6	13	25	31
		100	5	10	14	24	24
		150	0	0	5	20	30
	E	0	0	19	62	76	81
		50	6	6	13	25	31
		100	5	10	14	24	24
		150	0	0	5	20	30
East	N	0	0	0	17	17	35
		50	0	5	16	26	37
		100	0	0	6	6	12
		150	0	0	21	32	47
	S	0	17	39	61	72	72
		50	0	6	6	11	22
		100	5	5	16	21	26
		150	0	0	0	12	29
Control	mean		0	0	2	11	14.5

Figure 1.31. Phosalone trial. Total mortality, after 4 days, among aquatic invertebrates exposed to possible drift.
Key: Gf = Gammarus exposed in the field. All others were exposed later, to water samples taken from field targets: Gu = Gammarus exposed to undiluted target water: Gd = Gammarus exposed to diluted target water: A = Asellus exposed to undiluted target water: D = Dytiscidae larvae exposed to undiluted target water.

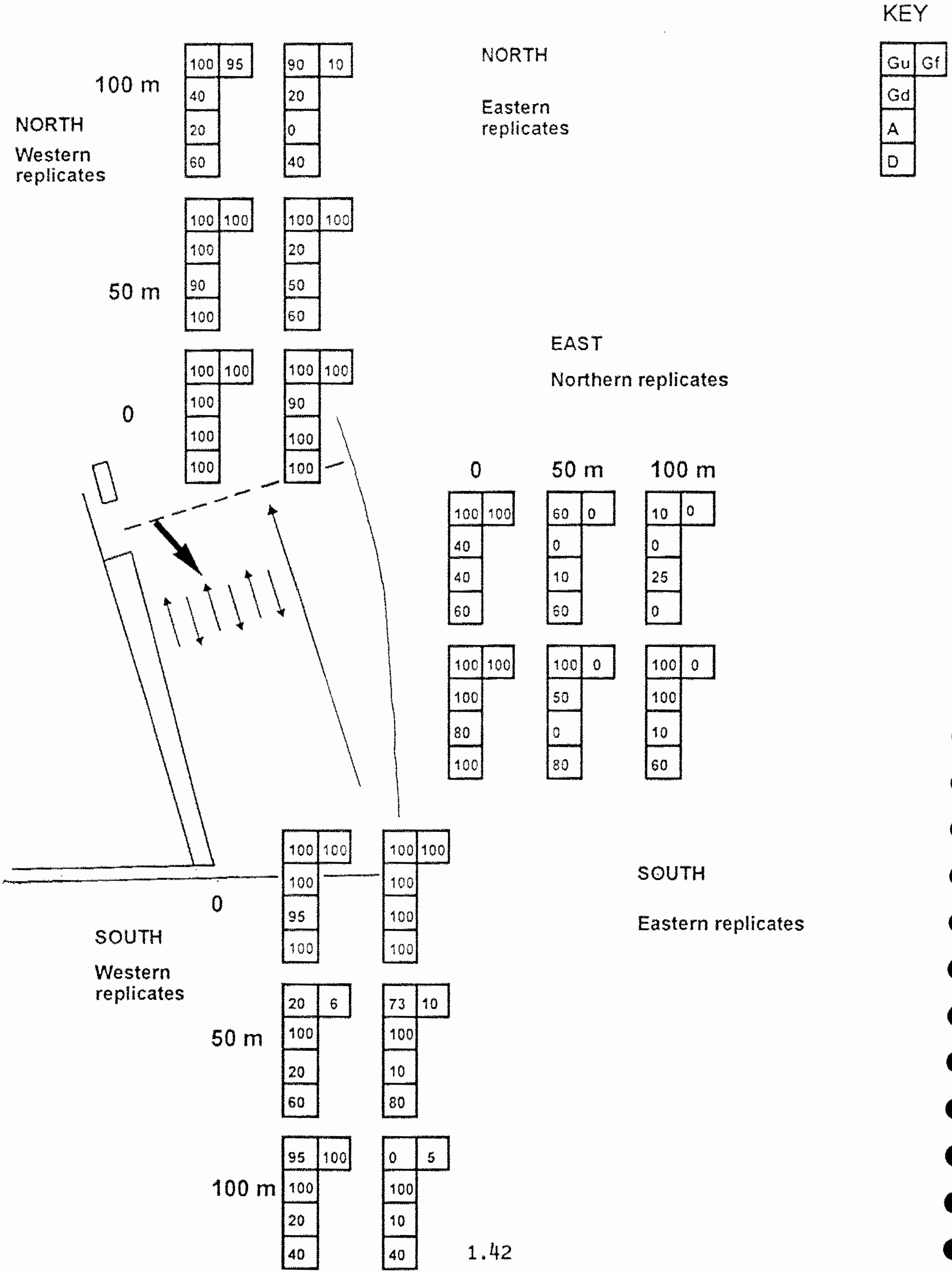


Table 1.5. Cumulative % mortality, over 4 days, among *Gammarus* exposed to possible phosalone drift in the field.

			Time (hours)					
Position	Replicate	Dist	4	24	48	72	88	110
In crop	W		100					
	E		100					
North	W	0	100					
		50	95	100				
		100	0	95	95	95	95	95
	E	0	0	100				
		50	0	100				
		100	0	0	5	5	10	10
South	W	0	100					
		50	6	6	6	6	6	6
		100	0	100				
	E	0	100					
		50	0	10	10	10	10	10
		100	0	5	5	5	5	5
East	N	0	0	100				
		50	0	0	0	0	0	0
		100	0	0	0	0	0	0
	S	0	0	100				
		50	0	0	0	0	0	0
		100	0	0	0	0	0	0
Controls			0	0	2.5	2.5	2.5	2.5

Table 1.6. Cumulative % mortality, over 4 days, among *Gammarus* kept in water samples that had been exposed to possible phosalone drift.

			Time (hours)				
Position	Replicate	Dist	20	44	66	88	110
In crop	W		100				
	E		100				
North	W	0	100				
		50	100				
		100	100				
	E	0	100				
		50	100				
		100	10	70	90	90	90
South	W	0	100				
		50	0	10	10	20	20
		100	0	90	95	95	95
	E	0	100				
		50	18	36	64	73	73
		100	0	0	0	0	0
East	N	0	50	100			
		50	0	30	60	60	60
		100	0	0	0	10	10
	S	0	100				
		50	20	60	100		
		100	20	60	100		
Controls			0	0	0	0	0

Table 1.7. Cumulative mortality %, over 4 days, among *Gammarus* kept in water samples that had been exposed to phosalone drift and diluted to simulate a depth of 25 cm of water in the targets.

Position	Replicate	Dist	Time (hours) 20	44	66	96
In crop	W		100			
	E		100			
North	W	0	100			
		50	100			
		100	0	20	30	40
	E	0	20	70	90	90
		50	0	0	20	20
		100	10	10	10	20
South	W	0	80	90	100	
		50	60	100		
		100	100			
	E	0	100			
		50	100			
		100	10	20	90	100
East	N	0	0	20	30	40
		50	0	0	0	0
		100	0	0	0	0
	S	0	50	100		
		50	0	0	20	50
		100	0	20	70	100
Controls			0	0	0	0

Table 1.8. Cumulative mortality (%), over 4 days, among *Asellus* kept in water that had been exposed to phosalone drift.

Position	Replicate	Dist	Time (hours)				
			20	44	66	88	110
In crop	W		90	100			
	E		90	100			
North	W	0	100				
		50	10	90	90	90	90
		100	0	0	20	20	20
	E	0	0	95	100		
		50	0	10	30	50	50
		100	0	0	0	0	0
South	W	0	95	95	95	95	95
		50	10	10	20	20	20
		100	10	20	20	20	20
	E	0	90	100			
		50	0	0	0	10	10
		100	0	0	0	10	10
East	N	0	10	20	40	40	40
		50	0	0	0	10	10
		100	0	17	17	25	25
	S	0	0	70	70	80	90
		50	0	0	0	0	0
		100	0	0	10	10	10
Controls			0	0	0	0	0

Table 1.9. Cumulative mortality (%), over 4 days, among *Dytiscidae* kept in water that has been exposed to phosalone drift.

Position	Replicate	Dist	Time (hours)				
			20	44	66	88	110
In crop	W		100				
	E		100				
North	W	0	100				
		50	100				
		100	0	0	40	60	60
	E	0	80	100			
		50	20	40	60	60	60
		100	20	20	20	40	60
South	W	0	100				
		50	0	20	60	60	80
		100	0	0	40	40	40
	E	0	100				
		50	0	0	60	80	80
		100	0	40	40	40	40
East	N	0	0	40	40	60	80
		50	0	60	60	60	60
		100	20	40	60	60	60
	S	0	60	100			
		50	10	60	60	80	80
		100	0	10	60	60	60
Controls			0	0	0	0	0

1.6.3 Discussion

It was expected that phosalone would be only moderately toxic to *P. brassicae* since it is not recommended for Lepidoptera pests of ground crops (Ivens 1993). The results generally bore this out since 100% mortality was limited to targets that were most likely to have received the full spray and was relatively slow to take effect. Nevertheless, significantly greater mortality than in controls was recorded 50 m upwind, 150 m downwind and up to 150 m from drift off the eastern edge of the field. The upwind results were clearly the result of over-spraying, and were probably in part attributable to difficulties in seeing the arbitrary boundary during spraying. At the downwind edge, the sharp drop in caterpillar mortality, from 80-100% to 31-33% at 50 m south of the plot, indicated a relatively precise cut-off at this clear boundary though mortality then showed little further decline up to 150 m. At the eastern field boundary, the caterpillars suffered quite low mortality (17%) for the first four days on the northern transect while those to the south had 72%. The 6-day mortality levels must be treated with caution because of the unusually high mortality among controls at the end of this period (Table 1.4).

It is difficult to derive definite buffer zones from this trial because of the lack of nil effects for *Pieris* on the transects. Variability of results between "replicate" target positions was due to the oblique flight path and wind direction in relation to the target lines. "Significant" mortality was recorded at 150 m on the eastern and southern transects, but as these arrays were both inclined at about 45° to the wind direction, this distance may be equivalent to 170 m downwind from the field edges. Indeed, as Figure 1.30 shows, the eastern targets were probably even further from the first spray swath, especially the water targets.

The high mortality among aquatic invertebrates at 100 m in the western replicate on the south side of the crop contrasts with the sharp drop in mortality among caterpillars beyond 50 m on this side. This illustrates still further the potential risk to organisms from over-spraying in at least one of the swaths as a result of failure to cut off the spray at the appropriate point, or possibly as a result of drift carried by turbulence created by the aircraft. If the latter is a factor it is likely that it would be more pronounced at low wind speeds. The data also demonstrate the substantial element of chance in these circumstances, in that there may or may not be an observable effect, depending upon the precise location of the experimental target.

1.7 FENITROTHION (1)

1.7.1 Methods

Spraying and sampling
This trial was actually the first to be carried out in 1993 (Table 1.3). It used almost exactly the same area as had been used for triazophos in 1992, but now under wheat, and the western half of the field used for the second fenitrothion trial described above (Figure 1.32).

Spraying was scheduled for 1100 and the laying out of targets therefore started at 0830 when the wind direction was almost due east. Because the targets in the triazophos trial had not been placed far enough downwind to obtain a no-effect distance, cabbage and water targets were placed up to 400 m downwind from the western edge of the crop through two wheat fields towards the Chatteris-March road (Figure 1.32). The closest water traps were placed at the edge of the sprayed field (at 0 m) and the closest cabbage plants at 5 m, across a ditch.

However, the very light wind continued to drop and just before the plane came the wind vane on the anemograph swung through 180°. The plane made nine passes starting about 20 m from the western edge but all the targets were upwind.

1.7.2 Results

No mortality occurred in *any* of the samples during the first few days. To test the efficacy of the concentrate, the original drum was recovered from Stibbington airfield and used at serial dilutions against the aquatic fauna. This showed that the chemical was highly toxic to *Gammarus* and *Asellus* at concentrations as low as 0.56 $\mu g\ l^{-1}$ of water. This is estimated to be about 6% of the concentration that would have resulted from direct spraying of the water targets.

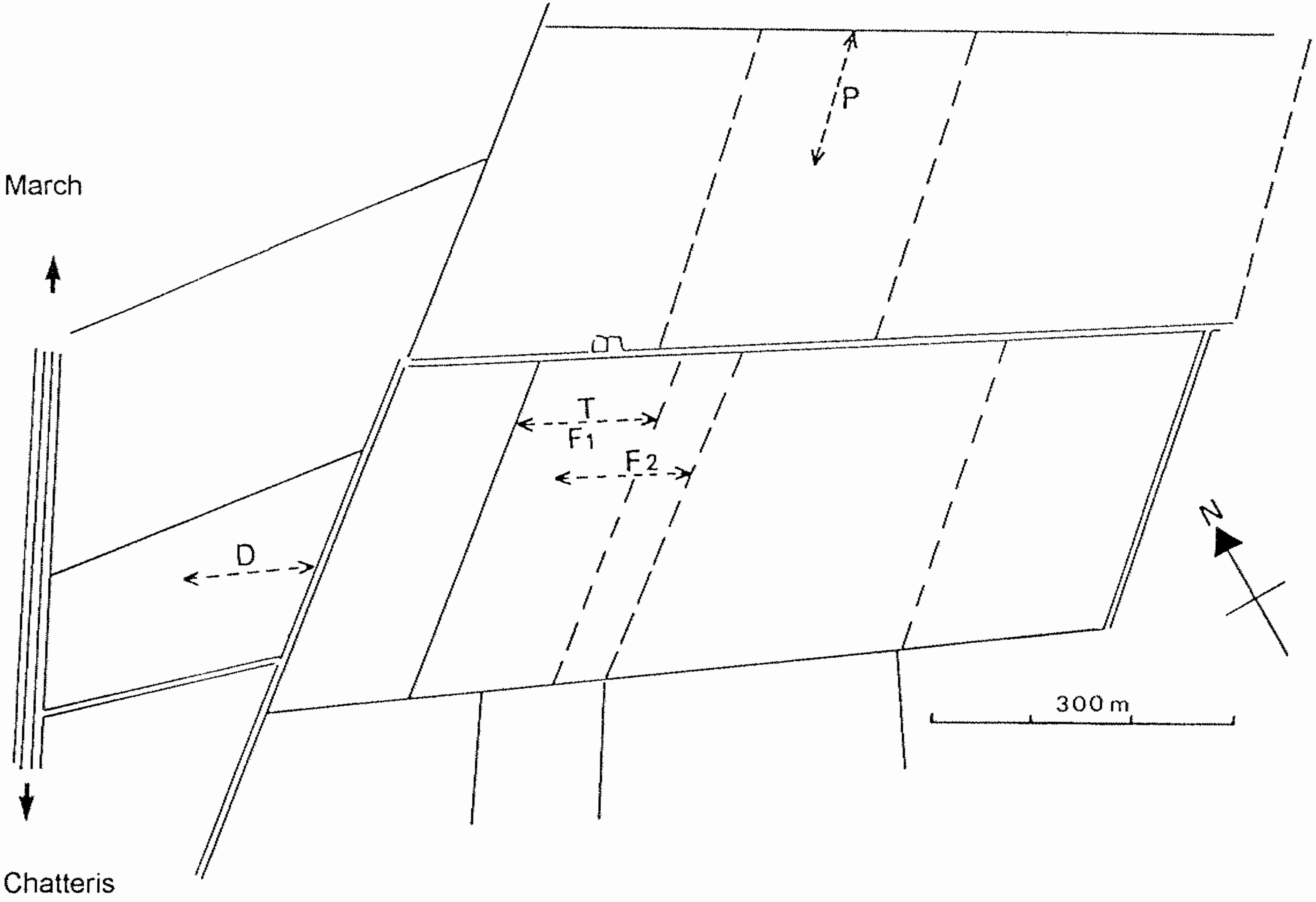
The main conclusion from this trial was that there is little or no upwind drift at right angles to the flight path from a fixed wing spray plane.

1.7.3 Discussion

This trial demonstrated the importance of determining the maximum effect by placing targets within the sprayed field itself. The previous trial (with triazophos) had produced 100% mortality in *Pieris* and *Gammarus* up to 100 m and the concern had been to spread out the limited number of targets so as to map the downwind mortality curve most efficiently.

The results also highlighted the need to try to validate the application rate by measuring the spray deposition within the crop. Since the insecticide itself could not be analysed, a tank mix was required which included a non-toxic tracer. A foliar nutrient was therefore considered which would be compatible with the insecticides used, was harmless (or even beneficial) to the crop, and which could be analysed by atomic absorption or ICP-MS.

Figure 1.32. Curf Fen showing fields and approximate widths used for five aerial spray trials: D = deltamethrin (1991), T = triazophos (1992), P = pirimicarb (1992), F_1 and F_2 = fenitrothion (1993). Broken lines indicate variable crop boundaries in 1992 and 1993.



The caterpillars from this last trial and some fresh aquatic fauna were therefore used in an experiment at Monks Wood to examine the possibility of using a manganese-based foliar nutrient (Mantrac) as a tracer in future trials. However, the aquatic fauna proved sensitive to the Mantrac and so this was not used.

1.8 PIRIMICARB

1.8.1 Methods

This was the third trial done in 1992 using a sugar beet field immediately north of the field described above for the triazophos and fenitrothion trials (Figure 1.32). According to the original contractual agreement, only caterpillars were used. An initial spraying date of 12 August had to be cancelled owing to a week of stormy weather. The trial took place on 26 August with 4-day-old *Pieris* larvae when the surrounding wheat fields had all been harvested. Weather conditions were cool with a brisk southerly wind, force 4. Three lines of targets 5 m apart were set out on the ground in the stubble to the north from 0-150 m downwind.

The plane made six passes all from east to west, using marker flags set out along the east edge of the crop and starting 36 m from the northern boundary to allow for drift into the crop. The number of larvae on each plant was recorded immediately after return to Monks Wood and for the following week.

1.8.2 Results

There was good larval survival at all distances; the mean mortality for controls was almost the same as the overall mean for the 27 exposed plants (Table 1.10). There was also no evidence of any inhibition of growth (as occurred with phosalone and fenitrothion); the majority of larvae were in late third or early fourth instar at the end of this period.

Half of the plants had moderate infestations of woolly aphids in the young leaves at the end of this period, including one plant at 0 m and two at 20 m distance. A patch of kale plants within the sprayed area was also found to have whitefly a week after spraying. Pirimicarb is not recommended for either of these pests which are controlled by a soap concentrate insecticide, "fatty acids".

1.8.3 Discussion

The efficacy of this application could not be checked since there was no aphid infestation in the sugar beet. However, Sinha *et al.* (1990) showed that *P. brassicae* was about 14 times less sensitive to pirimicarb than to phosalone in topical applications. The field application rate for pirimicarb is also five times less than for phosalone (Table 1.3). The relative "field hazard" of pirimicarb is therefore one seventieth that of phosalone and the results of this trial accord with expectation. The values in Table 1.4 are useful simply in demonstrating the natural variation in mortality with *P. brassicae* larvae in such trials, which involve considerable handling and movement of larvae and plants from the laboratory to the field and back.

Table 1.10. Bioassay of pirimicarb spray drift from aerial application. Percentage mortality of *P. brassicae* larvae after 7 days. Mean of 3 replicates.

Downwind distance	No. of larvae	% mortality
0	51	5.9
10	61	1.6
20	60	1.7
30	65	4.6
50	60	5.0
75	69	7.2
100	61	8.2
125	67	3.0
150	64	3.1
Controls	64	4.7

1.9 GENERAL DISCUSSION

1.9.1 Aerial spraying: experimental control and validation

The Holme Lacey trial showed the need for validating spray application rates, especially when direct comparisons are made between two treatments. Chemical assays of most pesticides require special techniques and facilities and have not been part of this Contract. However, in the absence of any confirmation of the correct application rate, results could be very misleading, either by underestimating or overestimating the "true" effects of drift arising from correct application rates. In this particular instance, we had the benefit of collaboration by MAFF Central Science Laboratory. We can therefore say that the aerial spraying gave relatively low estimates and the ground spraying relatively high estimates for deltamethrin drift to be expected under these weather conditions.

The anomalous mortality curves beyond 30 m in some of the bioassays of drift from the tractor obscure comparisons with results from the helicopter. Nevertheless, if the two treatments had had the same application rate, one may judge that there might be little difference in drift effects from aerial and ground spraying over the first 10-20 m owing to the relative positions of the first swath - in keeping with Mr M T Davies' original supposition. Beyond this, however, it is likely that there would be greater deposition and impact from aerial spraying.

In the absence of a sensitive chemical assay of pesticide drift, the next best approach would be the addition of a environmentally acceptable tracer in a tank mix (see the last asulam trial, Section 2). This still requires some development research to find a suitable material for insecticide trials which is both non-toxic to the bioassay species and can be applied to edible crops without commercial loss.

Failing both of these validation tests, one must rely on a contractor using a compound as he would in standard commercial practice following label recommendations. This is best achieved by using a full spray canister with the appropriate amount of water rather than trying to estimate partial doses. The use of targets within the sprayed area provides a check of maximum effect, measured (for insecticide bioassays) by the *rate* at which mortality occurs.

The use of water-sensitive papers is also a check that visible spray deposition has or has not reached a given target position. Their value was demonstrated in the second fenitrothion trial which involved English Nature staff. They would have been useful in the first fenitrothion trial in confirming the lack of upwind drift. However, they cannot always be used, eg when the vegetation is wet (as at Holme Lacey) or when there is high humidity (as in the 1991 deltamethrin trial). It is interesting to note that in the first of three aerial spray drift experiments by Riley *et al* (1989), the measured deposition of deltamethrin at 0 m (the theoretical edge of the target zone) was 4.4% of the nominal dose, while the deposition on the water-sensitive papers at 0 m in the second fenitrothion trial was 4.1% of the measured droplet deposition under the plane. However, Riley *et al* point out that this percentage value could be greatly affected by a few metres displacement in the position of the first spray swath.

Finally, the use of a "standard" site, and the cumulative logical pattern of data obtained from a series of trials, greatly help in interpreting the results obtained.

1.9.2 Bioassays

The first and last trials (with deltamethrin and fenitrothion 2) showed the relative sensitivity of bioassays compared with chemical assays and water-sensitive papers in detecting drift; in the former case, "no deltamethrin was able to be detected by any of the air sampling media at any distance downwind of the area treated by the ground based application" (Glass 1993), whereas 100% mortality was recorded in *Centroptilum* nymphs up to 30 m; in the latter case, five measurable spots on the water-sensitive paper at 100 m was associated with 87% mortality in *P. brassicae*.

Pieris brassicae larvae are reasonably robust and yet sensitive species for such trials. A major limitation is the need to plan well in advance so that fresh eggs are obtained about 5-6 days before a trial. This allows a tolerance of one or two days for the trial itself. A spell of unsettled weather entails at least two weeks delay before a second batch can be got ready - more if there is a gap in the egg production cycle by the commercial breeder. There is also a need to have a good stock of vigorous young cabbages; plants in poor condition can result in undue mortality among controls. Growing plants are better than cut leaves for bioassay observations lasting more than 2-3 days but even they will only suffice to feed 20 growing caterpillars for a limited period. Variability between plants inevitably leads to greater variability in larval exposure to drift and therefore to their response though this can be minimized by judicious pruning.

The bioassays involving aquatic invertebrates demonstrate the substantial variability that may exist between taxa in their susceptibility to pesticides. The mayfly *Centroptilum* and the mosquito *Culex torrentium*, for example, were more susceptible to the effects of deltamethrin and fenitrothion, respectively, than either of the crustaceans. In contrast, *Gammarus* was the most susceptible of the three test organisms used for bioassay in respect of triazophos. In this instance, both *Asellus* and mayflies (*Baetis* sp) showed similar sensitivity. In the determination of adequate buffer zones for aquatic communities, data from a single species could be very misleading. In situations where the desired outcome is the protection of a particular species, it will be necessary to be confident that the species in question is not significantly more vulnerable than those for which information is available.

For *Gammarus* in particular, the data suggest that stress from other causes, such as low oxygen concentration, may have a synergistic effect on mortality. For example in the phosalone trial, *Gammarus* exposed to contaminated water in the laboratory, even when this was diluted, suffered more mortality than those directly exposed in the field, perhaps because of the smaller beakers used (see Section 1.6.2). The use of several species for bioassay also provides additional data that allow such, apparently anomalous, results to be interpreted more easily.

In general, because of its relatively greater sensitivity to reduced oxygen concentration, and tendency for dead animals to decompose very rapidly (leading to a drop in oxygen concentration), *Gammarus pulex* was not an ideal organism to use in these bioassay experiments. More consistent results would have probably been achieved had it been possible to aerate the experimental containers. *Asellus*, which was used in all of the earlier laboratory-based experiments (Pinder *et al* 1993) as well as all of the aerial spraying trials, proved much more robust and gave consistent data. The only difficulty with this species was the frequent tendency to remain in a state of almost total paralysis, often for days, before dying.

All of the field experiments with aquatic invertebrates employed very shallow (2 cm deep) water. This has some advantages in that the relatively high concentration of pesticide in the contaminated water allows drift to be detected at considerably greater distances than is generally possible by chemical means or using water-sensitive papers (see discussion of deltamethrin trial). However, the data represent a substantially worse case than is likely to occur in a real field situation, where water bodies will generally be deeper, may be flowing and will usually contain organic sediment (onto which pesticides may adsorb). Even in the extreme conditions under which the bioassays were conducted, the aquatic organisms showed responses at distances similar to, or less than, those at which significantly mortality occurred among the caterpillars. It is reasonable to conclude, therefore, that buffer zones determined as being safe, on the basis of the *Pieris* data, will also be adequate for the protection of aquatic invertebrates.

1.9.3 Conclusions

The seven aerial insecticide spraying trials (including the 1991 deltamethrin trial) covered five compounds and a wide range of spraying conditions, from low to high wind speeds and unstable to neutral or even stable meteorological conditions. Together these throw light on "worst case scenarios", including the uncertainty of the direction of drift at the centre of a high pressure weather system. The results are therefore considered to have met the requirements of the Contract in allowing assessment of buffer zones, see Section 4.

Previous studies have determined the LD_{50} levels for all five compounds in topical applications to *P. brassicae* larvae (Sinha *et al* 1990, Davis & Pinder 1992). It is therefore possible to draw up a table to give "field hazard" ratings (application rate/LD_{50}), and to compare the observed percentage mortalities at different distances downwind (Table 1.11).

Table 1.11. Summary details of aerial spraying experiments with *Pieris brassicae* caterpillars to compare relative "field hazards" (rate/LD$_{50}$) and observed mortalities from drift.

Insecticide	Trial location and date	Application rate (g/ha)	*Pieris* LD$_{50}$ (μg/g)	Application rate/LD$_{50}$	Wind m/sec	Period mortality observed	Mortality of *Pieris* (%) at distance				
							Control	0 m	50 m	100 m	150 m
Deltamethrin	Chatteris 1991	7.9	0.049	161	0.4-2.0	12 h	0	100*	70	44	43
Deltamethrin	Holme Lacey 1992	2.7	0.049	55	1-1.5	7 d	9	89	10+	4	2
Triazophos	Chatteris 1992	295	1.52	194	2-4	4 d	12	100	100	100	97
Pirimicarb	Chatteris 1992	140	564	0.2	2.5-5.5	7 d	5	6	5	8	3
Phosalone	Abbots Ripton 1993	700	38.9	18	0.5-2.5	4 d	11	a) 87 b) 41	26 19	14 17	21 17
Fenitrothion (2)	Chatteris 1993	700	4.29	163	2.5-4.5	6 d	8	100	100	87	23

* at 4 m   + 32% at 40 m, 25% at 75 m
a) in line with flight path   b) at right angles to flight path
distances for both a) and b) need to be multiplied by 1.13 because of oblique wind direction ie 0, 57, 113, 170 m

The results are, of course, also affected by other factors especially weather (wind speed, atmospheric stability, humidity etc) and mode of action of the compound (persistence, stomach action etc). Nevertheless, a pattern of relationships can be seen when these are plotted (Figure 1.33). At zero distance (the nominal edge of the sprayed area) there is a strongly convex relationship - see the line joining open circles - showing that high mortality is quickly reached with increasing field hazard rating. For caterpillars at 50 m there is a linear or sigmoid relationship (triangles), at 100 m a weakly concave relationship (squares) and at 150 m a strongly concave relationship. Further data points are needed to obtain a clearer picture of the relationships for field hazard ratings of 55-160. However, it seems likely that any application with a rating >60 might cause 50+% mortality at 50 m, and doubling this rating might double the distance, ie 50% mortality at 100 m.

Some of the most toxic and wide spectrum compounds considered are no longer available for aerial application, or only for special purposes, eg against Colorado beetle. However, the principles can be widely applied and should at least be considered in the protection of sensitive sites.

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