# 6 EFFECT OF HEDGES ON SPRAY DRIFT

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## 6.1 BACKGROUND AND OBJECTIVES

There is considerable literature on the aerodynamics and micrometeorology of hedges and shelterbelts. The principles of air movement around such features are fairly well known (see Pollard, Hooper & Moore, 1974) and have been the subject of mathematical modelling (eg Plate, 1970; Wilson, 1985; McNaughton, 1989). When wind reaches a solid barrier, such as a wall, the moving air is all diverted up and over it giving strongly turbulent conditions behind it, and a rapid return to free wind speed (Fig. 6.1). For a permeable barrier like a hedge, some of the air filters through and so there is a lower pressure difference on the two sides and a more gradual return to free wind speed. The shelter effect is usually measured in terms of 'hedge height' units, H. Thus, a hedge of 40% permeability will reduce wind speed "significantly" for a leeward distance equivalent to 8-12 H (Marshall, 1967, quoted in Pollard *et al.*)

In addition to the reduction in wind speed on the leeward side of a hedge, there is also a reduction on the windward side due to a 'cushion' of air which diverts the moving air upwards. Pollard *et al.* state that this zone may extend for 4 H from the hedge, while Rider (1951) showed that such an effect could be detected for a distance of 10 H (17 m with a 1.7 m high hedge).

The effect of hedges on the deposition of spray particles has not been well studied, and there were two main objectives of this work. The first was to see whether a hedge a few metres downwind of a sprayed field would enhance or reduce the effect of pesticide drift at that distance as compared with the effect when there was no hedge there. The second was to study the shelter effect behind a hedge. The question of modelling the effect of hedges on the impact of spray drift would also be considered.

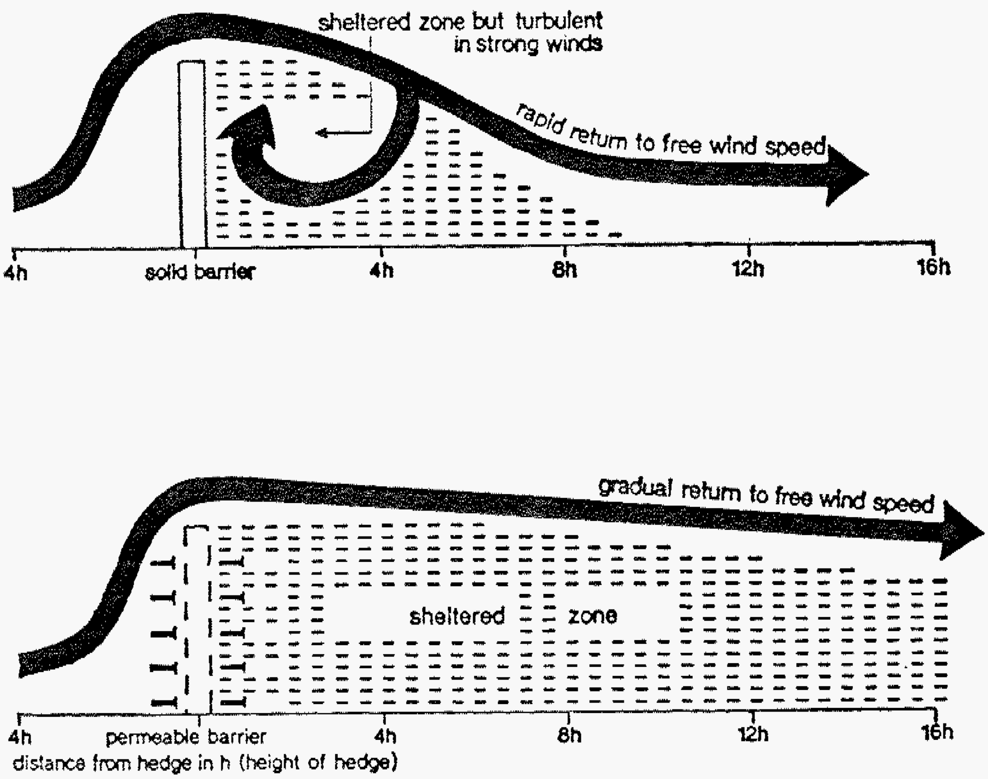
The following account is divided into three main sections. The first describes the use of fluorescent dyes for studying drift deposition in the presence and absence of hedges. Development aspects of this work are only briefly described; further details are given in Brown (1991). The second section describes bioassay experiments in relation to hedges. Finally, the Discussion considers the relative advantages of these two approaches, draws out the main conclusions, and points to further work that needs to be done.

Spray drift into woodland edges is considered briefly in an Addendum.

## 6.2 USE OF FLUORESCENT DYES FOR MEASURING SPRAY DRIFT

Fluorescent dyes and pigments have been used as spray tracers for over 35 years to assess deposits on plant surfaces (Sharp, 1974). A range of water soluble, oil soluble and insoluble particulate materials are now available that are non-toxic to plants and animals at the levels used, and can be detected at low concentrations. Recent developments in their use with fluorometry and photography were summarized in a series of papers given at a workshop on The Use and Limitations of Tracers for the Qualitative and Quantitive Assessment of Agricultural Spray Deposits organised by the Association of Applied Biologists and Shell Research in 1989.

Fig. 6.1. Wind shelter by solid and permeable barriers. The permeable barrier makes a more efficient shelter (From Pollard, Hooper & Moore, 1974).



Sodium fluorescein was chosen for the present work. It can be readily recovered from a range of natural and artificial targets using water with 0.02 M sodium hydroxide and a non-ionic surfactant (0.01% v/v 'Agrol'). A disadvantage is that dry deposits fade rapidly in sunlight, and field samples must therefore be placed in a dark container as quickly as possible.

Extracts from receptors were measured using a Shimadzu RF5001 PC Spectrofluorophotometer fitted with a 150 W Xenon lamp. Maximum fluorescence in solution occurs at an excitation of 483 nm and emission of 514 nm. By altering the sensitivity range, dye concentrations in the range 0.001-1 ppm could be measured.

6.2.1 **Comparison and choice of receptors**

**Methods** A variety of cylindrical collectors have been used in studies on spray drift, in addition to flat surfaces which are known to be inefficient, eg thin polythene tubing, pipe cleaners, test-tube brushes and hair curlers (Gilbert & Bell, 1988; May, 1991; Cross, 1991; Parkin & Merritt, 1988). These four types were therefore compared together with a metal receptor which could be useful for other studies involving direct analysis of organic pesticides, viz.

- Plastic rods 1.6 mm diam x 180 mm long
- Pipe cleaners 3 mm x 180 mm
- Test-tube brushes 10 mm x 100 mm
- Plastic hair curlers ('Cut-A-Roller') 38 mm x 60 mm
- Cylinders of aluminium mesh (David's Car Repair) 30 mm x 80 mm.

For the field trial, three parallel rows of stakes were set out 10 m apart in an area of short grass at 1, 2, 4, 8, 16 and 32 m downwind of the area to be sprayed. Each stake had a cross-bar 45 cm above ground-level from which the receptors were hung, one set each side in random order, using hooks or clips which facilitated removal without handling at the end of the trial. Two similar support masts were placed 20 m upwind of the sprayed area as controls.

Sodium fluorescein was used at 350 ppm in the spray tank, and spraying carried out in the standard way using a 6 m boom 0.75 m above the ground with operating pressure 2 bar giving an application rate of 150 litres $ha^{-1}$. The tractor made four passes going at least 50 m beyond the target lines in both directions. The receptors were then placed in glass storage jars in cardboard boxes. The whole operation took about 10 minutes.

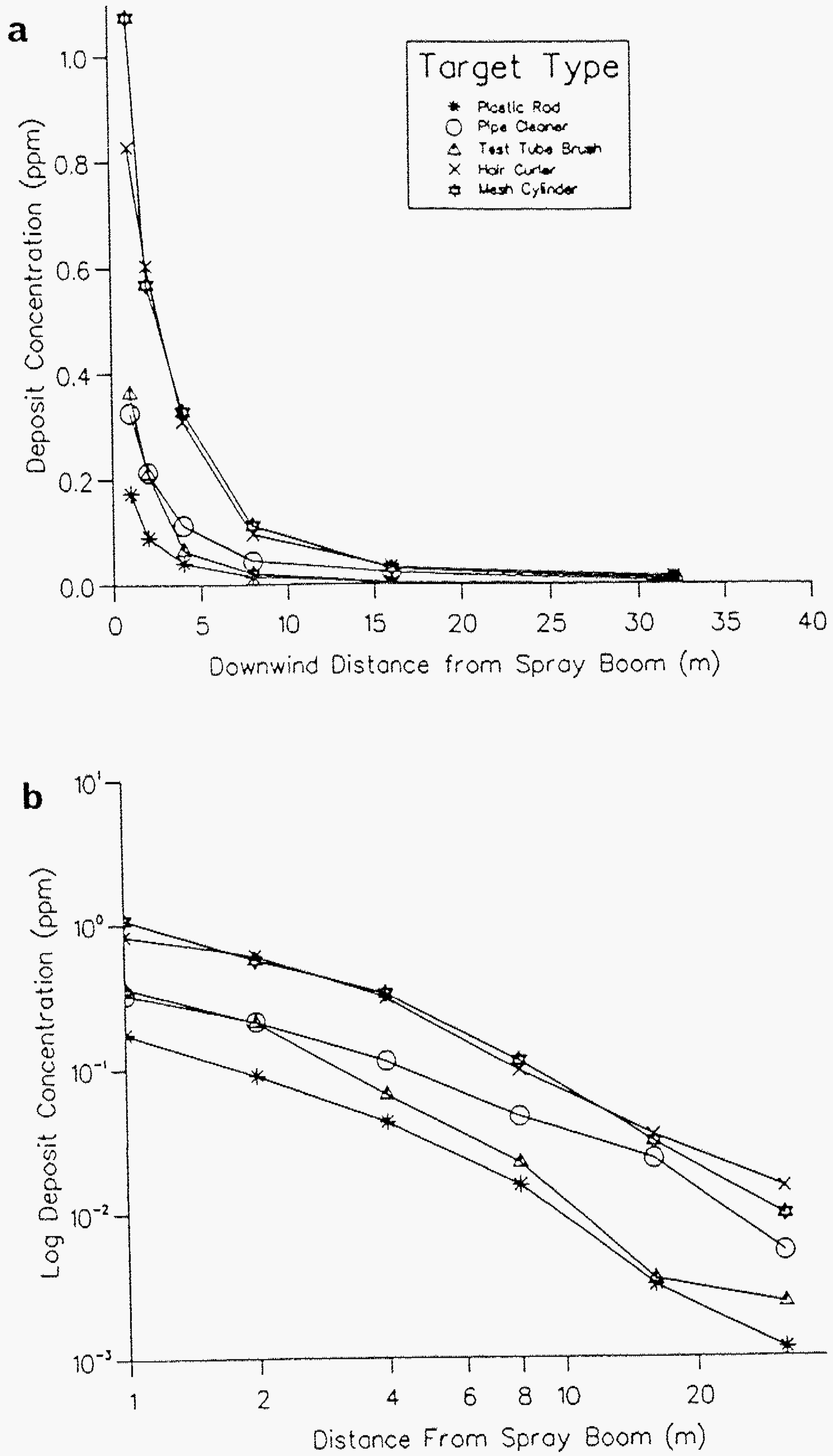
The spray deposits on the receptors were extracted by rinsing thoroughly in 15 ml of the washing liquor. The intensity of dye was measured in the fluorometer using the controls to check for background fluorescence. Intensity values were then converted to ppm from calibration graphs which had already been prepared from standard solutions. Recovery values for each type of receptor were obtained by spiking clean receptors with various concentrations of the spray solution, and fade was allowed for in a separate experiment by exposing samples in the field for known periods.

**Results** The results (Table 6.1) showed drift deposition levels ranging from 0.001 ppm for the plastic rods at 32 m distance to 1.08 ppm for the mesh cylinders at 1 m. Since the sprayer emission rate

Table 6.1. Mean spray drift deposits (ppm) (with standard errors) (n = 6) on 5 different receptors at increasing downwind distances from the spray boom (from Brown, 1991).

| Distance from Spray Boom (m) | Plastic Rod | Pipe Cleaner | Test tube Brush | Hair Curler | Mesh Cylinder |
|---|---|---|---|---|---|
| 1 | 0.174 (0.011) | 0.326 (0.065) | 0.158 (0.014) | 0.829 (0.160) | 1.076 (0.047) |
| 2 | 0.091 (0.009) | 0.213 (0.023) | 0.211 (0.051) | 0.605 (0.058) | 0.569 (0.061) |
| 4 | 0.043 (0.004) | 0.114 (0.009) | 0.066 (0.003) | 0.310 (0.020) | 0.330 (0.030) |
| 8 | 0.016 (0.001) | 0.050 (0.004) | 0.022 (0.003) | 0.096 (0.006) | 0.113 (0.008) |
| 16 | 0.003 (0.0008) | 0.018 (0.006) | 0.004 (0.001) | 0.034 (0.006) | 0.031 (0.003) |
| 32 | 0.001 (0.0001) | 0.005 (0.0004) | 0.002 (0.0004) | 0.015 (0.003) | 0.010 (0.002) |

Fig. 6.2. Relationships between fluorescein dye collected by five types of receptor and distance downwind from a sprayed area (means of 6 replicates). Results plotted on normal scales (above) and log scales (below). (From Brown, 1991).



was 350 ppm, these values represent 2.9 x $10^{-6}$% and 3.1 x $10^{-3}$ of emission rate respectively. All receptors showed an exponential decline in dye collected with distance (Fig. 6.2a). There was little difference between receptors in sampling efficiency at different distances as shown by the nearly parallel curves in Fig. 6.2b, but since the larger receptors collected larger deposits the hair curlers were selected for future experiments.

### 6.2.2 Hedge effects on drift deposition

**Methods** Experimental hawthorn hedges at Monks Wood were laid in March 1991 for these studies. When in leaf, they produced dense, even barriers ca. 1.6 m high x 1.2 m wide. These hedges were 30 m apart except at the western end where one was cut down completely to give a 60 m fetch from the tall boundary hedge.

Two series of drift experiments were carried out using fluorescein. The first series used a continuous length of hedge to examine both vertical and horizontal profiles of drift particles. The second series compared the difference between drift over a hedge and drift through a gap where the hedge had been removed.

The first series consisted of three trials done at different wind speeds when the direction was suitable, ie roughly at right angles to the hedges. In each case, the sprayer made four passes covering an area 24 m wide starting 6 m from the hedge. The field procedures were similar to the previous experiment except that pairs of hair curler receptors were hung from cross-bars at 0.45, 1.0 and 2.0 m height to obtain data on the vertical profile of the drift clouds. In each trial, two lines of support masts were set out 10 m apart, and within each line the targets were placed at 1, 5, 6, 7, 10, 15 and 20 m downwind of the sprayed area, those at 6 m being hung at the upwind edge of the hedge or immediately above the hedge. A chart anemometer gave a continuous record of wind speed and direction at 1.5 m height and 6 m in front of the hedge, while four counting anemometers recorded mean wind speeds at 0.45 and 1.0 m heights at 10 and 15 m behind the hedge.

The second series of trials was also done on three occasions. One line of paired receptors passed across a section of hedge as before, while a second line, 20 m away, passed through the centre of a 16 m wide gap. The receptors were placed at the same heights and downwind distances as in the previous series but not in the line of the hedge itself. Wind speeds at 0.45 and 1.0 m heights on the two transects were measured only at 10 m behind the line of the hedge.

**Results** Continuous hedge trials

The meteorological data from the first series of hedge trials are given in Table 6.2, and the deposition results illustrated in Fig. 6.3. (For both series, the results are described in order of ascending wind speed for convenience of interpretation.) At the lowest wind speed, deposition on the two lower lines of receptors showed similar trends: a steady fall off up to the hedge, a sudden large decrease immediately behind the hedge, and then a gradual increase up to 20 m distance. Note the logarithmic scale for deposition; on an arithmetic scale this increase is scarcely noticeable. There was less drift deposition on the highest receptors in front of the hedge but this increased slightly where

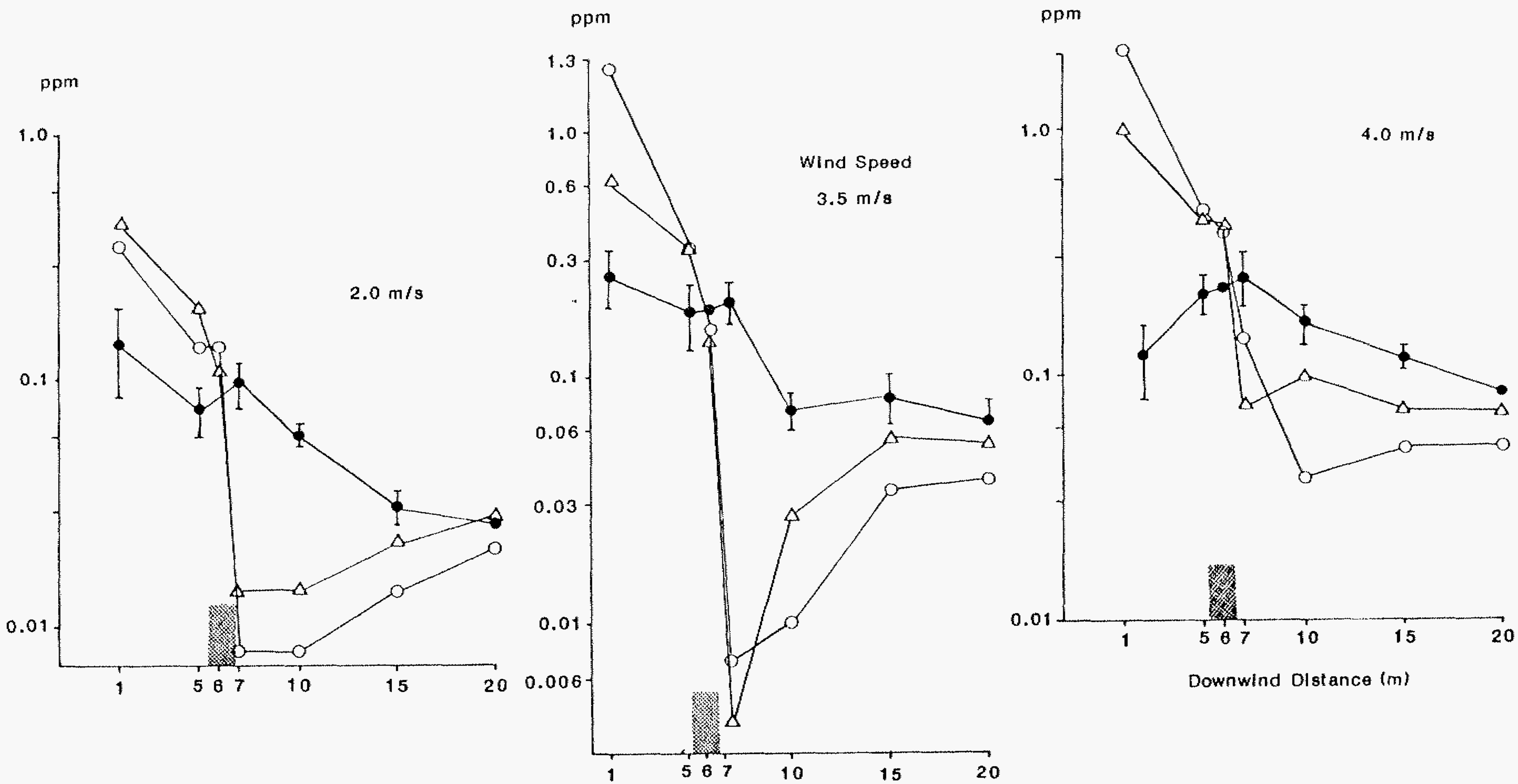
Table 6.2. Meteorological data for fluorescein trials with continuous hedge 6 m from sprayed area. Sunshine on scale 0-4. (From Brown, 1991).

| Trial | Distance<br>Height | Wind speed ($ms^{-1}$) at 3 distances (m) downwind of sprayed area<br>0<br>1.5 | 10<br>0.45 | <br>1.0 | 15<br>0.45 | <br>1.0 | RH% | °C | Sunshine |
|---|---|---|---|---|---|---|---|---|---|
| 3 | | 2.0±1.0 | 0.5 | 0.7 | 1.1 | 1.7 | 78 | 18 | 3 |
| 2 | | 3.5±1.5 | 1.2 | 1.7 | 2.4 | 3.2 | 82 | 19 | 2 |
| 1 | | 4.0±2.0 | 1.9 | 2.6 | 3.1 | 3.6 | 70 | 27 | 4 |

Table 6.3. Fluorescein drift deposition (ppm) at given distances from a sprayed area along a transect across a laid hedge. Totals of amounts collected at 0.45, 1.0 and 2.0 m heights above the ground at three wind speeds. (Means of 4 replicates).

| | Wind speed $m\ s^{-1}$ | | |
|---|---|---|---|
| Distance (m) | 2 | 3.5 | 4 |
| 1 | 0.922 | 2.706 | 3.256 |
| 5 | 0.411 | 0.848 | 1.099 |
| 6 (Hedge) | 0.336 | 0.483 | 1.007 |
| 7 | 0.120 | 0.217 | 0.465 |
| 10 | 0.081 | 0.109 | 0.297 |
| 15 | 0.066 | 0.171 | 0.237 |
| 20 | 0.075 | 0.153 | 0.203 |

Fig. 6.3. Fluorescein drift deposition in relation to a continuous hedge (shown stippled). Results from three trials at different wind speeds each with receptors at three heights: ○ = 0.45 m, Δ = 1.0 m, ● = 2.0 m.



the air currents passed over the hedge, and then fell more gradually to about the same level as the lower receptors at 20 m.

Essentially similar profiles were recorded at the intermediate wind speed though there was greater initial difference in deposition at the three receptor heights, almost identical values at the hedge itself, and a more marked shelter effect and recovery behind the hedge for the two lower receptors.

At the highest wind speed, the hedge appeared to offer rather less shelter to the two lower receptors, and there was little or no subsequent increase in deposition. There was considerably less drift deposition initially at 2.0 m height than at the lower heights or in the earlier trials (as would be expected), but deposition increased up to the hedge before declining again gradually.

The total amount of drift deposition at all distances (sum of the receptors at three heights) increased with wind speed (Table 6.3).

Hedge versus gap trials

The second series of trials provided nine comparisons of deposition profiles in the presence or absence of a hedge, ie results for three heights on three occasions (Fig. 6.4). The wind speeds varied less than in the first series, the highest being 3.0 m $s^{-1}$ which is more within acceptable limits for spraying (Table 6.4).

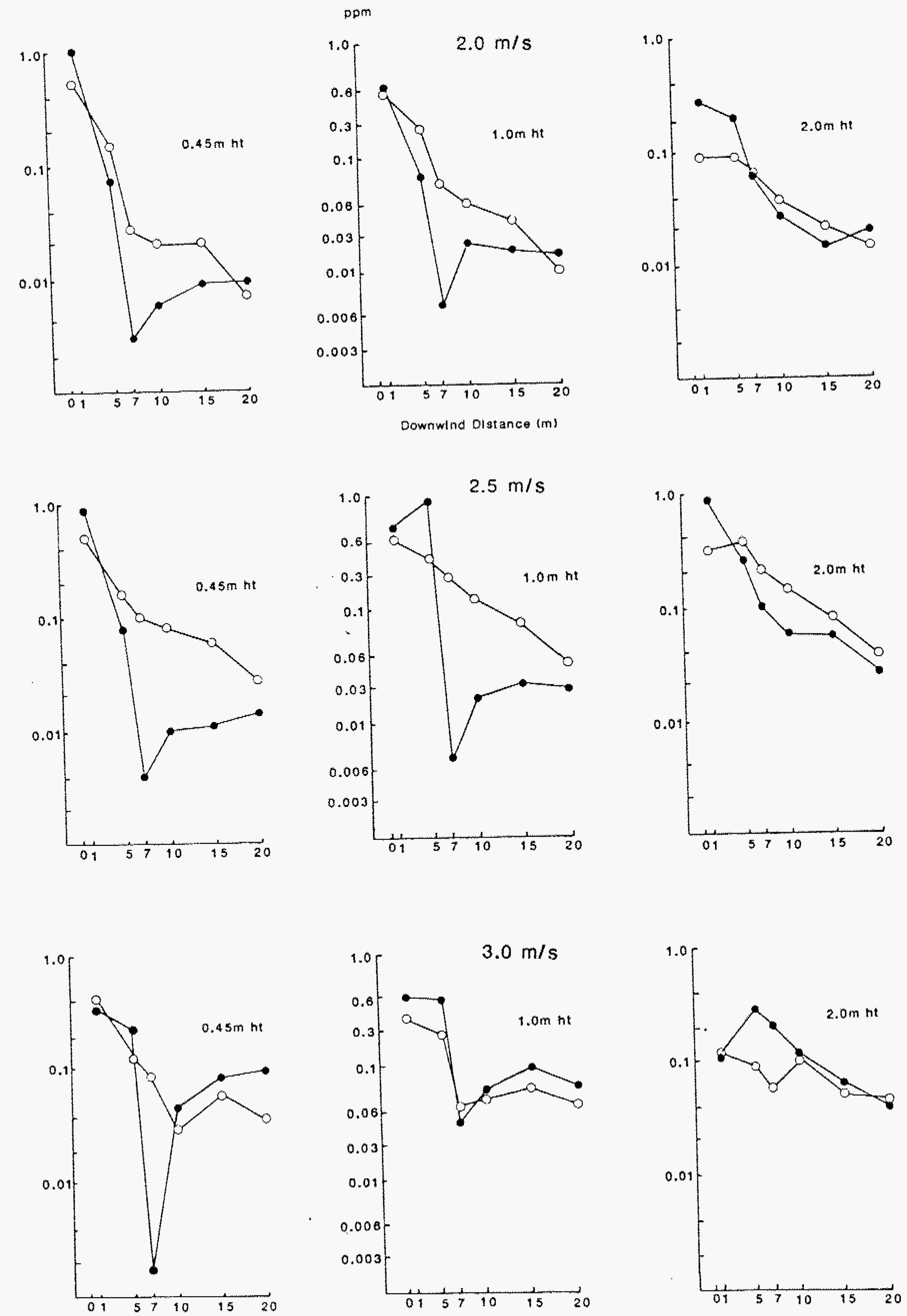
For the receptors at 0.45 m height, the shelter effect of the hedge at 7 m can again be clearly seen in all three trials in contrast with the more gradual decline in deposition in the gap. The subsequent increase behind the hedge up to 20 m was also evident, and in two cases the deposition even exceeded that in the transect line through the gap.

Table 6.4. Meteorological data for fluorescein trials with alternating hedge and gap 6 m from sprayed area. Sunshine on scale 0-4. (From Brown, 1991).

| | | Wind speed ($ms^{-1}$) at given distances (m) downwind of sprayed area | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | In gap | | | Behind hedge | | | | |
| Trial | Distance<br>Height | 6<br>1.5 | 10<br>0.45 | 10<br>1.0 | 10<br>0.45 | 10<br>1.0 | RH% | °C | Sunshine |
| 3 | | 2.0±1.0 | 1.67 | 1.87 | 0.6 | 0.9 | 67 | 25 | 2 |
| 2 | | 2.5±1.25 | 1.6 | 1.9 | 0.45 | 0.7 | 84 | 22 | 4 |
| 1 | | 3.0±1.5 | 2.7 | 2.4 | 0.78 | 1.1 | 90 | 17 | 0 |

The same comparisons can be made for the receptors at 1.0 m height except that, at the fastest wind speed, there was also a sudden drop in deposition at 7 m in the gap. This effect, which was seen to a

Fig. 6.4. Fluorescein drift deposition in relation to a hedge (solid circles) and a gap (open circles). Results from three trials at different wind speeds each with receptors at three heights. Hedge at 6 m distance.



lesser extent at 0.45 and 2.0 m, may be due to lateral turbulence from the hedges on either side of the gap.

For the highest receptors, the deposition profiles over the hedge and through the gap were generally more alike, as one would expect since they were above hedge height. In both transects, the deposition at 2.0 m height was higher than that at 0.45 m at most distances from 5-20 m downwind of the sprayed area (23/30 cases). Thus, although the larger droplets sediment out quite quickly, the finest particles are carried up by turbulent air flow and must contribute to low level pollution over long distances.

## 6.3 BIOASSAYS

Five bioassay experiments were made, one with MCPA and plants and four with cypermethrin and *Pieris brassicae* larvae. In all cases, lines of targets were laid out in an area of short grass across adjacent sections of hedges and gaps as described above. However, in one of the cypermethrin trials there was very little wind and no effects attributable to drift were recorded so these results are not reported.

### 6.3.1 Plants

**Methods** Seeds of tomato (variety Alicante) and *Lychnis flos-cuculi* were sown in trays of ICI potting compost in August 1991 and kept in an unheated glasshouse. Slow germination of the *Lychnis* and then unsuitable weather for several weeks delayed the field trial until 4 November. (Conditions were either too calm or too windy or the wind was parallel to the hedges rather than at right angles.) By this time, the tomato plants were about 30 cm while the *Lychnis* rosettes were about 8 cm across.

Spraying was carried out as in the previous trials starting 6 m from the hedge line and making four passes covering a 24 m wide area. Four lines of plants, about 18 m apart, were placed opposite four alternating sections of hedge and gap. In each line, three trays of both species were placed (in random order) at 1, 5, 7 and 15 m downwind of the sprayed area, those at 5 and 7 m being immediately in front of and behind the hedge (or gap). The 15 m position was chosen as a result of the fluorescein trials which showed an increased deposition at this distance from the sprayer, ie 8-9 m behind the hedge (Fig. 6.3). MCPA was applied as in previous herbicide trials (Marrs *et al.*, 1989) except that a tank pressure of 3 bar was used to obtain a finer spray which would accentuate drift.

After spraying, the trays were taken back to the glasshouse and kept for one week. Individual plants were then scored as showing severe damage, slight damage or no damage using the criteria as in Table 6.5. It was assumed that severely damaged plants would either die or be severely retarded in growth while slightly damaged plants would probably recover after a check.

Table 6.5. Damage criteria for MCPA spray drift on tomato plants and *Lychnis flos-cuculi* rosettes after 1 week.

| | |
|---|---|
| | Tomato |
| Severe: | Twisted growing points, swollen leaf axils, pale colour of tips. |
| Slight: | Slight bending of tips but no discolouration |
| | Lychnis |
| Severe: | Flaccid, dark, crinkled leaves |
| Slight: | Slightly darkened but crisp leaves |

**Results** Wind conditions during spraying and the results of the trial are summarized in Table 6.6. Only a few tomato plants were completely unaffected in the transects across the hedges up to 15 m, and none in the transects through the gaps (Fig. 6.5). However, there was a big difference in the proportions of severely damaged plants at 7 m, followed by a significant increase again behind the hedge between 7 and 15 m ($P<0.05$).

The *Lychnis* plants were less obviously affected than the tomato plants: 5-8% showed only slight damage at 1 m, and 36-52% showed slight or no damage at 15 m. The shelter effect of the hedge at 7 m was again very clear (Fig. 6.5), and there was again an increase subsequently resulting in similar levels of damage at 15 m behind the hedges and through the gaps.

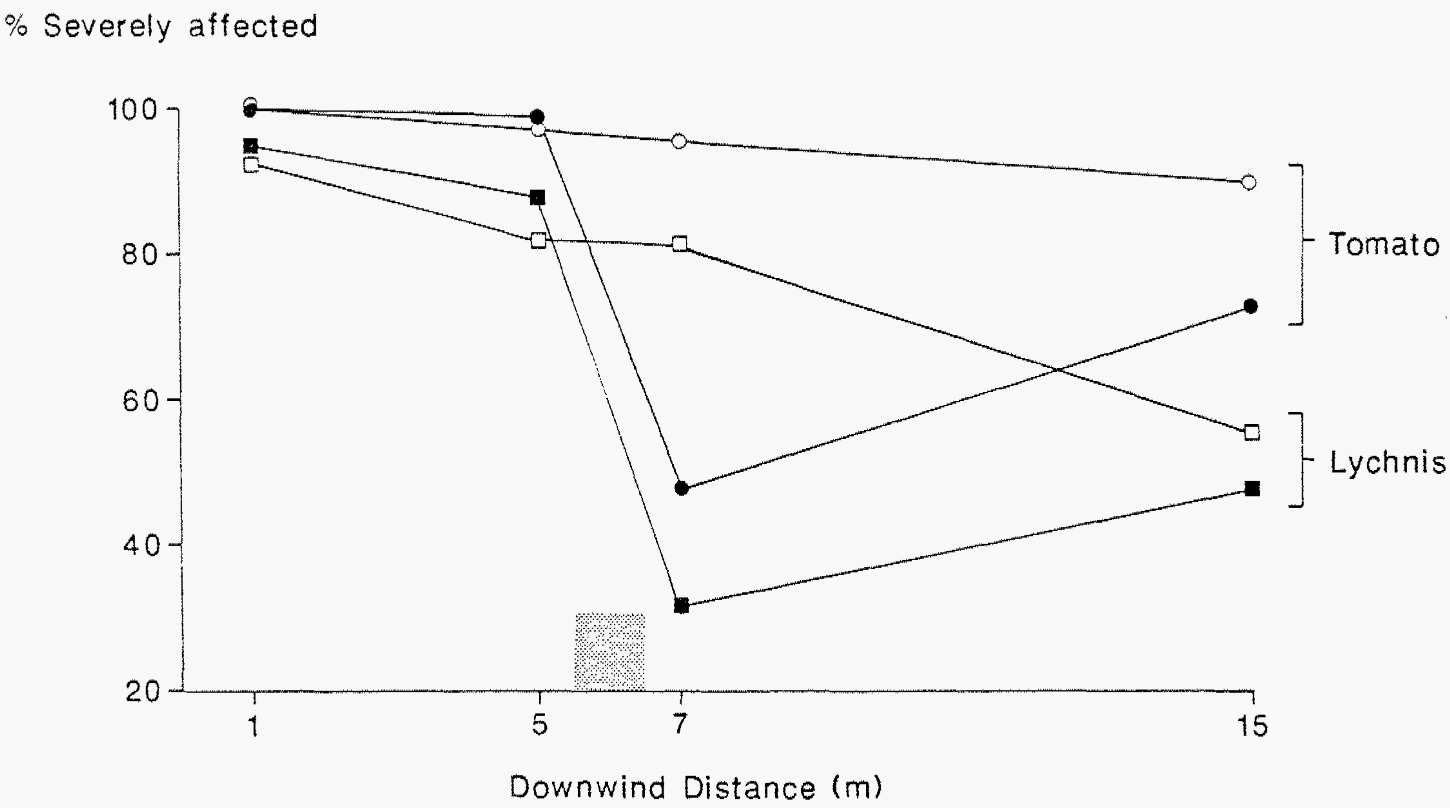
Analysis was undertaken on the angularly transformed proportions of seriously affected *Lychnis* plants using a regression modelling approach. The addition of a cubic term for the hedge transects gave a significant improvement on a model using only quadratic terms ($F_{1,11} = 15.48$, $P<0.01$). The parameters of the cubic relationship suggest that the apparent increase in damage at 15 m compared with 7 m was a real one.

Table 6.6. Numbers of tomato and *Lychnis* plants affected by MCPA spray drift at given distances downwind of a sprayed area at Monks Wood 4.11.91. Sum of 2 transects (3 trays of plants per station) across sections of hedge or through gaps, with the hedge line at 6 m. Wind speed 3.5-4.0 m $s^{-1}$. Damage ratings ++ = severe, + = slight, 0 = unaffected.

| | Tomato | | | | | | Lychnis | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Hedge | | | Gap | | | Hedge | | | Gap | | |
| Distance (m) | ++ | + | 0 | ++ | + | 0 | ++ | + | 0 | ++ | + | 0 |
| 1 | 113 | 0 | 0 | 115 | 0 | 0 | 729 | 41 | 0 | 557 | 47 | 0 |
| 5 | 111 | 1 | 1 | 108 | 3 | 0 | 582 | 89 | 0 | 568 | 124 | 13 |
| 7 | 53 | 55 | 4 | 111 | 5 | 0 | 211 | 336 | 128 | 523 | 100 | 22 |
| 15 | 82 | 28 | 3 | 104 | 12 | 0 | 263 | 233 | 55 | 402 | 285 | 50 |

Unaffected control plants: tomato 59, Lychnis 353

Fig. 6.5. Bioassay results for tomato and ragged-robin (Lychnis flos-cuculi) receiving MCPA drift in relation to a hedge (solid symbols) or a gap (open symbols) at 6 m.



### 6.3.2 Insects

**Methods** Two drift experiments were done in 1990 using a section of trimmed hedge ca 2.4 m high and an adjacent gap, while the third was done in 1991 using sections of laid hedge and gap as in the drift trials with dyes and MCPA reported above. In the first two cases, three lines of target leaves with caterpillars were placed 5 m apart opposite a single section of hedge and another three lines in the adjacent gap. (Ideally, replicated sections of hedge and gap would be used in randomized pairs but this was not feasible). Within each line, targets were placed at 1, 5, 7 and 11 m downwind of the sprayed area, those at 5 and 7 being on either side of the hedge line. The targets at 1 and 11 m were placed on the ground in the usual way, but, because the hedge was very open at the bottom (due to rabbit browsing), all the targets at 5 and 7 m were suspended from tripods at 1 m above the ground.

In the third trial, more emphasis was placed in detecting any increased mortality after the initial shelter at 7 m behind the hedge. Single lines of targets were placed opposite the centre of a laid section of hedge and adjacent gap at 3, 5, 7, 9, 11, 14, 17 and 20 m. All targets were on the ground, and, since the wind speed was low, 3 bar pressure was used to accentuate drift.

**Results** The results of the first two trials with the tall, unlaid hedge are shown in Fig. 6.6. The first trial indicated a strong shelter effect at 7 m where the mortality values for the hedge and gap series differed most strongly. However, there was also considerably higher mortality in the gap series at 5 m which suggests there was more drift along that section of the tractor run anyway.

The second trial was at a higher wind speed and there was a corresponding higher mortality at all distances compared with the first trial. In this case there was no clear shelter effect at 7 m, given the higher mortalities in the gap series at 1 and 5 m. However, there was apparently a big shelter effect behind the hedge at 11 m. (The increase in mortality for the gap series between 7 m and 11 m was statistically significant but not very informative because of the different heights of the receptors).

In the 1991 trial, there was much lower mortality at 5 m and 7 m, immediately in front of and behind the laid hedge, than in the series passing through the gap (Fig. 6.7). This suggests that the hedge was providing a protective cushion of air deflecting drift over the hedge as well as giving shelter for several metres behind it. However, this interpretation must be treated with caution owing to the lack of replication. As in the herbicide bioassay (Fig. 6.5) there was an increase in observed mortality 10 m behind the hedge (17 m from the sprayed area).

Fig. 6.6. Two bioassays of cypermethrin drift in 1990 with Pieris brassicae larvae in relation to a hedge (solid symbols) or gap (open symbols). Targets at 1 m and 11 m were on the ground, those at 5 m and 7 m were 1 m above ground. Means and standard errors of 3 replicates. Control mortality zero in both trials.

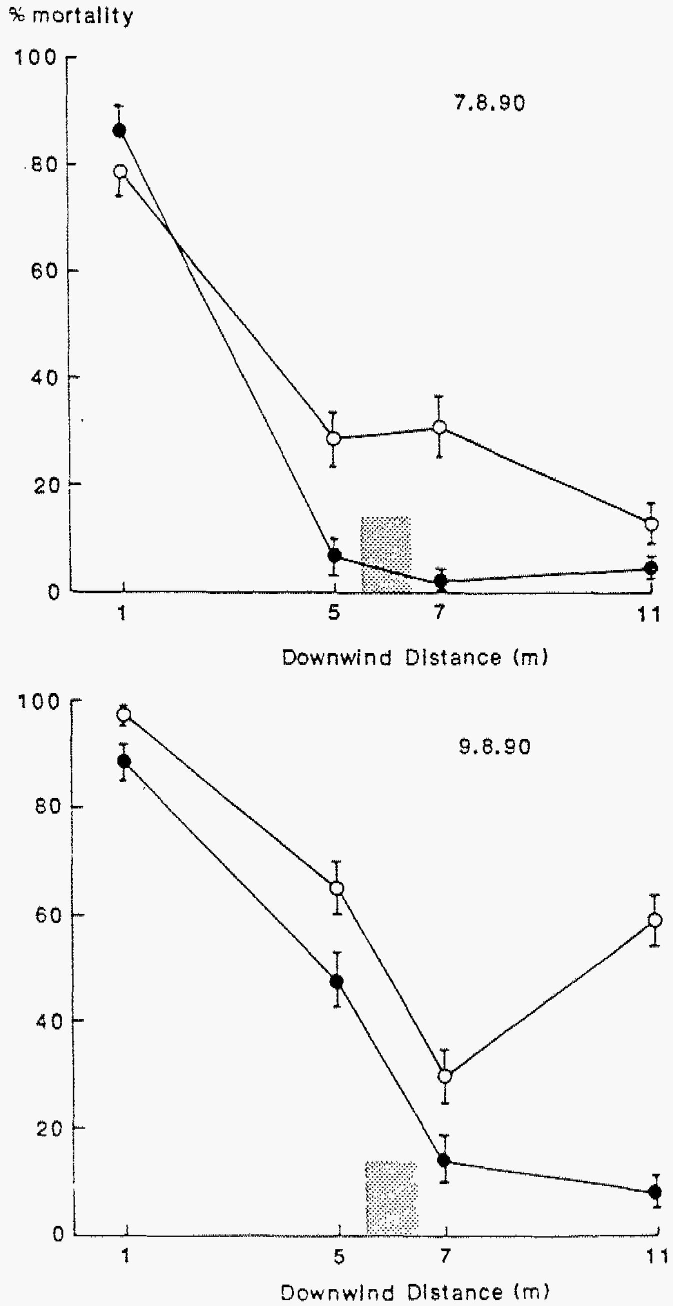
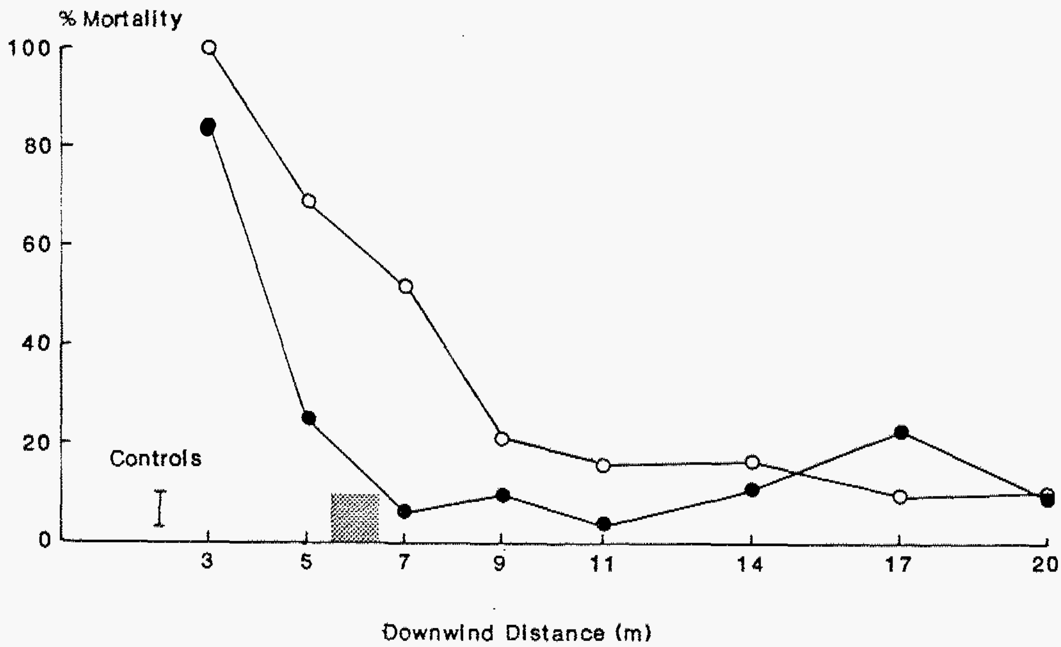


Fig. 6.7. Bioassay of cypermethrin drift in 1991 with P. brassicae larvae in relation to a hedge (solid symbols) or gap (open symbols).



## 6.4 DISCUSSION

The laid hedges at Monks Wood were thicker than many hedges in arable areas in Cambridgeshire, though less thick and tall than some of those at the Boxworth EHF near Cambridge, for example. There is no easy way of measuring the permeability of a natural hedge, and this probably alters with increasing wind speed anyway. However, the Monks Wood hedges may have had a permeability of about 40% in which case, according to Marshall's (1967) estimates quoted earlier, one would expect their effect to be observed up to 13-19 m downwind. In the continuous hedge trials, the 1 m high anemometers placed 15 m downwind gave readings of 85-91% of the free wind speed (in front of the hedge) (Table 6.4) which agrees quite well with the above estimates.

The use of a tracer dye in these studies has great advantages over bioassays in that the receptors are uniform and are available whenever weather conditions are suitable. Results can also be obtained within two days. Even so, it was often necessary to wait for a week or more between trials for the wind direction to be roughly at 90° to the experimental hedges. For the first series of trials, using a long uniform hedge, target lines could be laid out obliquely without incurring too many problems, though wind turbulence would be more complex. For comparing hedges and gaps, however, any deviation from 90° leads to increasing uncertainty in locating the hedge "shadow" with increasing distance downwind.

Replication in individual experiments was often inadequate to show statistically significant differences in fluorescein deposition at different distances, or at the same distances behind hedges and gaps as the actual values were very low. However, the consistent form of the results obtained in both series of fluorescein trials (Figs. 6.3, 6.4) is strong evidence for a hedge effect occurring up to about 20 m (12.5 H) downwind, at least at lower wind speeds. At speeds of $\geq 3$ m $s^{-1}$ the shelter effect appeared to be reduced, presumably because more wind blew through the hedge carrying fine droplets which impacted on the receptors.

Once the main features of drift deposition were determined in relation to hedges, bioassay trials could be designed to measure the impact of drift at appropriate positions. This is easier to do with plants than with insects because the former can be more easily kept until there are suitable conditions. On the other hand, deaths of insects of standard age are a more certain measurement of spray drift than arbitrary levels of damage to plants of variable age.

Again, the accumulated evidence from several bioassay trials demonstrated a sheltered zone downwind of the hedge where plants and insects were protected from the full effects of spray drift. In the case of very sensitive species (such as tomatoes to MCPA) and strong winds, the protection may be quite limited, and serious damage inflicted over considerable distances despite the presence of a hedge. In other cases, the sheltered zone may extend to the point where 'normal' drift deposition (in the absence of a hedge) is reduced to sublethal levels so that a hedge provides a high degree of protection. In intermediate cases, such as the *Lychnis*/MCPA results, a protected zone is followed by a zone of further significant damage. The effects of spray drift would then decline again to zero at greater distances, though our trial did not extend far enough downwind to show this under the prevailing conditions.

Rider's (1951) observations of reduced wind speed in front of a hedge, caused by back wind pressure, imply that heavier spray droplets should sediment out more quickly. This should result in plants or insects in the hedge bottom receiving less than they would in the absence of a hedge. The effect on deposition near the top of the hedge is less predictable. Our measurements of drift deposition at the upwind edge of the hedge at heights of 0.45 m and 1 m, and the plant bioassay results, were not distinguishable from those obtained in the gaps, but the low mortality in front of the hedge in the last cypermethrin bioassay would fit this interpretation. The higher spray pressure used on that occasion would have produced finer droplets that were more readily carried over the hedge. In any case, these combined results indicate that an unsprayed buffer zone before a hedge would be at least as effective as predicted from estimates made in open areas.

### 6.4.1 Models

A model for drift deposition in the presence of a hedge must consider the following variables: hedge height, hedge permeability, wind speed and width of buffer zone, in addition to the usual operator-controlled variables affecting spray output (Sinha, Lakhani & Davis, 1990). Since droplets decrease in size through evaporation with distance from the spray nozzle, their behaviour in relation to wind movements is clearly difficult to model from first principles (cf. Walklate, 1991). Their biological impact will furthermore depend on target sensitivity in a non-linear manner, as in the case of $LD_{50}$ or damage measurements from topical dosing of insecticides or herbicides.

An alternative approach is to combine the dye with a herbicide or insecticide, and to model the relationship between deposition and biological effect under simple site conditions, ie in the absence of hedges etc. Assuming that there is no interaction between dye and pesticide, such a relationship could be used to predict biological effects from studies with dyes alone in more complex situations. This has yet to be done, but offers major rewards in extending the scope and generality of drift studies. A pilot trial showed that MCPA itself fluoresced so it may sometimes be possible to measure pesticide drift directly using fluorometry. This could be of value not only in studying herbicide drift under farming conditions but also possibly in examining deposition on plant surfaces themselves.

### 6.4.2 Conclusions

This series of controlled experiments with deposition measurements and bioassays demonstrate a significant shelter effect immediately behind a hedge, followed by a zone of gradually increasing exposure to drift. This zone continues up to a distance of five to eight times the hedge height before declining again. In many cases, the protection afforded would be very effective as the dose received downwind of the hedge would never reach critical levels. With strong winds and highly toxic compounds, however, the protection would be quite limited. A tall hedge with around 50% porosity would be more effective than a low hedge with high porosity or a stone wall with very low porosity.

In practice, any hedge will provide a degree of protection to an adjacent downwind habitat. However, the survival of particular plants or animals in the proximity of crops will depend on the chances of exposure from recurrent spraying. Thus, if a hedge fails to provide adequate protection in spring when spraying takes place, its shelter effect the rest of the year is of little value. This cannot be tested in single controlled experiments. The siting of plant microcosms over considerable periods around the edges of nature reserves that border on sprayed crops would be a possible way of studying the impact of herbicide spray drift.

## 6.5 ADDENDUM: DRIFT INTO A WOODLAND EDGE

A pilot trial was carried out in one of the clearings in Monks Wood (East Field) to measure the extent of spray drift into a woodland edge. This was done by spraying water over the tall grass/herb vegetation of the clearing 5 m from the eastern edge on 10 October 1990, and measuring drift deposition with water-sensitive papers. The woodland along this edge consisted mainly of small birch and aspen trees with a grassy ground vegetation; it was not as open as is much of the western perimeter of Monks Wood where standard ash trees dominate over a ground cover of dog's mercury.

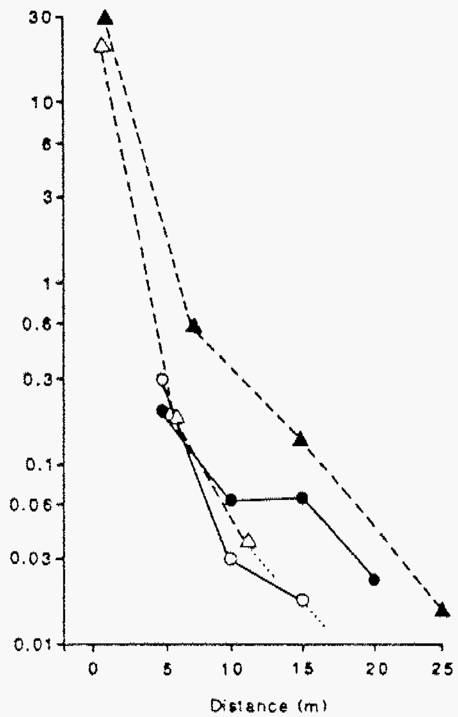
The tractor made two passes covering 12 m width with the spray boom about 30 cm above the vegetation (90 cm above the ground). This was then repeated with the boom raised to 60 cm above the vegetation. Wind speed was 3 m $s^{-1}$ on both occasions. Two lines of water-sensitive papers were laid out on each occasion, at 5 m (at the woodland edge), 10, 15 and 20 m from the sprayer. They were oriented to face the sprayer at about 70 cm above the ground and 20° from the vertical.

The drift depositions at 5 and 10 m were similar to those received at Upper Caldecote 2 when brussels-sprouts were sprayed, but considerably less than the mean values obtained from Haverhill 1 and 2 when peas were sprayed (Fig. 6.8). The mean deposition at 15 m on the first occasion was very similar to that measured at 10 m at Swavesey when peas were sprayed with triazophos. The mean larval mortality at that distance was 24%.

Such extrapolations are very unreliable but they suggest that pesticide drift could penetrate woodland edges and have effects on fauna and flora. More drift, and greater penetration, might occur if there were bare ground between a sprayed crop and the wood edge instead of the tall vegetation that there was in the clearing.

Another attempt was subsequently made to measure drift into the western edge of Monks Wood with water-sensitive papers when the adjacent farmer sprayed a cereal field with herbicide. However, spraying was delayed several hours through equipment breakdown during which time the wind dropped and became almost parallel with the wood edge. This, coupled with extreme caution in spraying by the farmer, resulted in negligible drift into the wood.

Figure 6.8. Spray drift into Monks Wood from East Field. Water droplet deposition on water-sensitive papers. Trial 1 ●——● , trial 2 ○——○ compared with mean values obtained at Upper Caldecote 2 △- - - - -△ and Haverhill ▲- - - - -▲. See section 4.



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